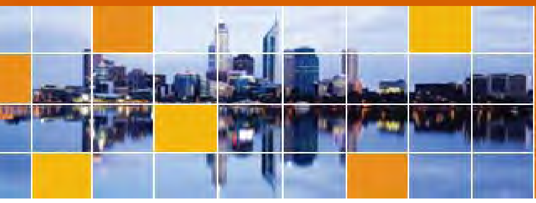

7TH INTERNATIONAL SYMPOSIUM ON DIGITAL EARTH

IN CONJUNCTION WITH:

Proceedings of the 7th International Symposium on Digital Earth (ISDE7)

Perth, Western Australia, 23 August – 25 August 2011

Edited by D. Shepherd, G. West, M. Johnston

Supported by

Government of **Western Australia**
Western Australian Land Information System

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Published by: WALIS Office, Landgate, PO Box 2222, Midland WA 6936, Australia

ISBN: 978-0-646-57316-8

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PREFACE

Venue and Delegates

The 7th International Symposium on Digital Earth (ISDE7) was held from Tuesday, 23 August to Thursday, 25 August 2011, at the Perth Convention and Exhibition Centre, Perth, Western Australia. A total of 485 delegates from 21 countries attended, including over 100 speakers from China, Europe, the United States, Japan, Brazil, Iran, Korea, Singapore, Australia, and New Zealand.

Opening Ceremony

The official opening of the conference took place on Tuesday, 23 August 2011. A Welcome to Country ceremony was performed in the Riverside Theatre by James Webb who represented the Elders from the Wadjuck region. The Minister for Lands, the Hon Brendon Grylls then officially launched the event, speaking about the Digital Earth vision and how far technology has evolved since VP Al Gore launched the vision in 1998.

The Minister acknowledged the major challenge identified in the original Digital Earth Vision; which is how to take advantage of the deluge of location-based information that's now available and make sense of it, and then turn that data into information that helps us make critical decisions.

Minister Grylls then spoke about the Location Information Strategy for Western Australia and our unique State. WA's dispersed population provides challenges in how to deliver infrastructure and services and products to our economic markets here and overseas efficiently from many locations across the State. It follows that the more we know about a location, where events occur and how they affect the people and assets at those places; the better we can plan, manage risk and use our resources.

The Minister then reaffirmed the commitment of the WA Government to support the expanded use of location-based technology, and noted that the same approach is being adopted in Australia and overseas. The rapidly increasing pace of technological innovation will continue to offer new opportunities that will support our local communities and economy, but this can only happen if we find new ways to turn data into useful information and put that information in the hands of individuals.

Following the Minister's official launch of the ISDE7 Conference, Professor Guo Huadong, Secretary General of the International Society for Digital Earth, thanked outgoing President Professor Lu for his service to the Society and announced the new President of ISDE as Professor John Richards from the Australian National University. Professor Richards then launched the Digital Earth Vision 2020, noting that the organisation is entering the next phase of development of ISDE.

The Digital Earth Vision 2020 was launched after more than 6 months of discussions from Digital Earth scientists worldwide. Professor Richards explained that the Digital Earth Vision 2020 will act as the geographical framework on which to build solutions to physical, social and cultural problems. The Digital Earth of the future will extend to underground and underwater environments; and provide both a historical perspective, and predictive capabilities. Importantly Digital Earth in 2020 will bring-together inherently non-visual data, provide a foundation for analysis and debate. Digital Earth will incorporate local information on place, culture, identity and networks.

Sponsors

The Organising Committee thanks the following agencies for their support of the ISDE7 Conference incorporating WALIS Forum 2011 and the State NRM Conference:

Gold Sponsor:	Caring for our Country
Silver Sponsors:	esri Australia Landgate
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Conference Program Structure

ISDE7 was held in conjunction with the 2011 WALIS Forum and State Natural Resource Management Conference. The WALIS Forum is one of the longest running, premier spatial conference events in Australia; and celebrated a major milestone in 2011 with the 30th Anniversary of the establishment of the unique and highly successful WALIS partnership.

The combined event also celebrated the successful long-term use of spatial technology to support natural resource and environmental management. This is particularly well developed in Australia, a globally recognised home to biodiversity; where spatial technology underpins the management of the vast, sparsely populated regions that drive the local economy.

The conference also expanded international cooperation through the establishment of a framework for cooperation in joint investigations and scientific exchange concerning earth observation science and technologies between Australia, Brazil, Canada and China. The Australia-Brazil-Canada-China (ABCC) workshop was held as a concurrent session during the conference. The ABCC Program was formed in response to the impacts resulting from global change that have emerged as a major priority for Governments and research organisations around the world. This international network of organisations document, study, monitor and assess the impacts of global change, and work together to improve systems, models and applications to identify those which would be most effective over the long term.

Several other meetings and events were held during, and in conjunction with the conference, including:

- ISDE Executive Committee
- CRC-SI Board Meeting

- The CRC-SI hosted the Spatial Innovation & Industry Development Workshop hosted by the CRC-SI. At this workshop participants obtained a preview into the CRC-SI Industry Development Program and contributed to future initiatives. Professor John van Genderen discussed China, *"a spatial perspective on emergent research, government and user markets and how to access those markets"*, Arpad Barabas from Canadian research industry organisation Tecterra discussed planned Australian industry outreach activities and international links and opportunities in China and Canada were explored.
- The Surveying and Spatial Sciences Institute (SSSI) WA Region hosted the Combined Spatial, Cadastral & Engineering Surveying Commissions Event - an event on Mapping for Heritage, Water and Forensic Investigations Using Modern Technology. The speakers were Peter Muirden, Department of Water, *"The WA Coastal Plain Lidar Dataset"*; Senior Constable Steve Marks, Forensic Field Operations, Western Australian Police, *"Forensic Surveying"*; and Elizabeth Lee, Director of Projects and Development, CyArk, California USA, *"Surveying and Mapping of World Heritage Sites by CyArk"*.

The conference program was comprised of plenary sessions on each of the three days, which included five keynote addresses. Six concurrent streams were held each day, which contained 20 different themes. Within these themes, 146 oral presentations were scheduled.

As part of the conference, a well-populated trade exhibition was held, which showcased the best of Australian and international innovation and expertise in spatial technology.

The full conference program is outlined below.

ISDE7 CONFERENCE PROGRAM

DAY ONE: TUESDAY 23 AUGUST 2011

8:00 - 8:30	**Registration**							
8:30 - 8:40	**Welcome - MC** ***Riverside Theatre***							
8:45 - 10:15	**ISDE Welcome Ceremony** **Welcome to Country** **Our World Presentation** **Official Opening - Hon Brendon Grylls Minister for Lands** **Launch of Digital Earth Vision 2020, ISDE President** ***Riverside Theatre***							
10:15 - 11:00	**Keynote: Chris Holmes (OpenGeo), Building the Same Digital Earth – spatial data infrastructure and architectures of participation** ***Riverside Theatre***							
11:00 - 11:30	**Morning Tea** *sponsored by* ***Spatial Vision***							
11:30 - 12:15	**Keynote: Elizabeth Lee (CyArk),** ***Digitally Preserving Cultural Heritage Sites*** ***Riverside Theatre***							
	Digital Earth Vision ***Riverside Theatre*** **Chair: Gerry Gannon**	**NRM** ***Riverview Rooms 4 & 5*** **Chair: Piers Higgs**	**Digital Earth: the Urban Environment** ***Meeting Rooms 1 - 3*** **Chair: Dr Marnie Leybourne**	**Data Management** ***Meeting Room 6*** **Chair: Paul Duncan**	**Health** ***Meeting Room 7*** **Chair: Dr Grace Yun**	**Digital Earth: the Marine Environment** ***Meeting Room 8*** **Chair: Jenny Smith**	**Workshop 1** ***Meeting Room 9***	**Workshop 2** ***Meeting Room 10***
12:15 - 12:45	Keynote: Professor Guo Huadong (ISDE) Digital Earth: *From Theory to Action - a digital earth science platform in CAS*	*Maximising the Economic Value of Biosolids: creating catchment and waterway restoration, climate adaptation, and business improvement – all at once!* Dr. Bob Humphries	*The Path More Travelled* Sharyn Hickey	*Landgate's Cartographic Enhancement Process* Susan Burrows	*Spatial Resolution, Health Informatics and Privacy* Narelle Mullan	*Performance of DEM Generation Technologies in Coastal Environments* Prof. Clive Fraser		
12:45 - 13:15	Keynote: Professor Li Deren (ISDE) *From Digital Earth to Smart Earth*	*Achieving Better Environmental and Sustainability Practices for SMEs* Scott Favacho	*Are our Neighbourhoods Liveable?* Paula Hooper	*Effective Agency Collaboration in Managing the State's Topographic Database* Marty Stamatis	*Healthtracks - can you see Health?* Shannon Carter	*WA Node of Australian Ocean Data Network* Luke Edwards	*Getting Your Paper Published - an editor's view* A.P. Cracknell - University of Dundee, UK Sponsored by International Journal of Remote Sensing	
13:15 - 13:45	Keynote: Dr. Max Craglia (ISDE) *A European Journey Towards Digital Earth*	*Total Resource Management* Kathe Purvis	*Road Rage or New Age* Mathew Linnane	*A Remote Sensing-Based Global Agricultural Drought Information System* Dr. Meixia Deng	*We Are What we Eat* Damber Shrestha	*The Construction of GIS-Based Marine Exploration Data* Dongil Kim		
13:45 - 14:45	**Lunch**							
	Digital Earth Vision ***Riverside Theatre*** **Chair: Gerry Gannon**	**NRM** ***Riverview Rooms 4 & 5*** **Chair: Damian Shepherd**	**Digital Earth: the Urban Environment** ***Meeting Rooms 1 - 3*** **Chair: Mark Taylor**	**Data Management** ***Meeting Room 6*** **Chair: Peter Ingwersen**	**Mining and Minerals in Digital Earth** ***Meeting Room 7*** **Chair: Stephen Bandy**	**Digital Earth: the Marine Environment** ***Meeting Room 8*** **Chair: Rodney Hoath**	**Workshop 1** ***Meeting Room 9***	**Workshop 2** ***Meeting Room 10***
14:45 - 15:15	Keynote: Michael Haines *Virtual Australia: a tool for the 21st Century*	*Sustainable Farm Practices - a model for success* Sandy Pate	*A Framework for Mapping and Modelling Informality in the Urban Century* Dr. Richard Sliuzas	*Why Land and Property are not the Same?* Simon Young	*3D Mineral Map of Australia* Dr. Thomas Cudahy	*Building and Progress of the China Digital Ocean Information Infrastructure* Xiaoyi Jiang		*Screening of 'Greener Horizons' – five wheatbelt farmers tell their tree crop stories.* Monica Durcan A different story every 10 minutes: 14:50 – Andrew and Suzi Sprigg of Bonnie Rock 15:00 – Kingsley Vaux of Ongerup 15:10 – Norm and Trudi Quicke of Kulin 15:20 – Michael Hogan of Bencubbin 15:30 – Ian Hall of Aldersyde
15:15 - 15:45	*Towards the Digital Earth - a virtual tour on HUNAGI blog posts* Dr. Gabor Remetey-Fulopp	*Using the Carbon Farming Initiative to Support Wetland Restoration* Dr. Robert Wocheslander	*Sydney Down Under - enabling the third dimension* John Moore	*WA's Street Address Improvement Program* Dr. Lesley Arnold	*Classification and use of Landform Information* Deanna Tucker	*GIS-Based Database Construction to Support Decision-Making on the Maritime Boundary Delimitation* Dongchul Lee		
15:45 - 16:15	*The Future of Earth Sciences* Dr. Robert Bishop	*Using Carbon and Water Ecosystem Services to Restore Catchment Function* Prof. Richard Harper	Keynote: Prof. Dr. Manfred Ehlers *Simplifying and Exchanging 3D Utility Network Using City Models*	*OneMap* Nelson Liew	*Model of Searching for Optimal Vehicle Route* Assoc. Prof. Marian Rybansky	*Creating a Marine Habitat* Falak Sheth	*Digital Cities Working Group Workshop on Digital Cities Objectives* Richard Simpson	
16:15 - 16:45	*Stepping up: tackling the growth challenges that really matter* Dr. Peter Woodgate	*The Farm Practice Change Model: a method for achieving sustainable agriculture outcomes in the Western Australian Wheatbelt* Dr. David Grasby	*Automatic Generation of 3D City Models* Prof. Kenichi Sugihara	*Positional Accuracy Improvement* Chee Ng	*Comparison of Relative Radiometric Normalisation Methods* Nisha Bao	*Research and Realisation of Visual Digital Ocean* Feng Zhang		
17:00 - 19:00	**Welcome Reception** *sponsored by* ***PSMA***							

** SSSI CPD Points for Day One: 6.5 points*

DAY TWO: WEDNESDAY 24 AUGUST 2011

8:00 - 8:30	**Registration**							
8:30 - 8:40	**Welcome - MC** ***Riverside Theatre***							
8:40 - 9:00	**Keynote: Jack Dangermond (Esri), *The Geographic Approach* *(Pre-recorded Video Presentation)*** ***Riverside Theatre***							
9:00 - 9:45	**Keynote: Ian Jackson (OneGeology Executive, British Geological Survey), *Liberating Rocks – the exploitation of geoscience data for societal benefit*** ***Riverside Theatre***							
9:45 - 10:30	**Keynote: A/ Prof. Linlin Ge (University of NSW), *Near Real Time Mapping of Recent Flooding Events in Australia with Satellite Radar Interferometry*** ***Riverside Theatre***							
10:30 - 10:45	**Discussion Time** ***Riverside Theatre***							
10:45 - 11:15	**Morning Tea** *sponsored by* ***Spatial Vision***							
	Digital Earth and the Changing World ***Riverside Theatre*** **Chair: Gerry Gannon**	**Digital Earth in Space** ***Riverview Rooms 4 & 5*** **Chair: Matt Adams**	**NRM** ***Meeting Rooms 1 - 3*** **Chair: Erin Devlin**	**ABCC Scientific Workshop** ***Meeting Room 6*** **Chair: Dr. Peter Woodgate**	**The Social Impacts of the Changing World** ***Meeting Room 7*** **Chair: Rob Freeth**	**Spatial Data Infrastructure (SDI)** ***Meeting Room 8*** **Chair: Kylie Armstrong**	**Workshop 1** ***Meeting Room 9***	**Workshop 2** ***Meeting Room 10***
11:15 - 11:45	Keynote: Dr. Robert Kay *Helping Pacific Islanders Visualise Potential Futures: using spatial tools to assess climate change impacts and adaptation responses in the Republic of Kiribati*	Keynote: Michele Clement *Digital Earth in a Space Policy Context*	*Knotweed in Agricultural Land* Kelli Gillies	*Climatological Analysis of Satellite-Based Snow Cover Parameters Over the Tibet Plateau* Dr. Qiu Yubao	*Addressing the Skills Shortage* Alan Smart	Keynote: Roland Slee (Oracle) *Next-Generation Spatial Data Infrastructure - Oracle Spatial Applications on Exadata and Exalogic*		
11:45 - 12:15	*Understanding the Impact of Volunteered Geographic Information During the Queensland Floods* Dr. Kevin McDougall	*The Achievements and Future Prospects of China Space Optical RS Technology* Feng Zhou	*Bullsbrook Biodiversity Corridor* Bonny Dunlop-Heague	*A Data Assimilation Approach for Producing Daily Snow Cover Maps Using the Canadian Meteorological Centre Snow Depth Analysis and Daily Satellite Observations* Rasim Latifovic	*Developing a Land Account for Australia* Mark Lound	*The Pioneering Relationship Between PSMA and Eurogeographics* Sallie White		
12:15 - 12:45	*The Future of GIS* Paul Farrell	*Research on the Construction of Virtual Lunar Environment Platform* Dr. Min Chen	*Lake Mealup Recovery Program* Agnidhar Bhandari	*Muztaga Glacier Velocity Extraction Based on the Offsets Derived from SAR Images* Dr. Li Xinwu	*Collaborative Slum Mapping with Google Map Maker* Dr. Richard Sliuzas	*ANZLIC Economic Assessment* Martin van Bueren	*O-Spec and Prelude to B-Spec* George Havakis	*Screening of 'Greener Horizons' – five wheatbelt farmers tell their tree crop stories.* Monica Durcan A different story every 10 minutes: 12:20 – Andrew and Suzi Sprigg of Bonnie Rock 12:30 – Kingsley Vaux of Ongerup 12:40 – Norm and Trudi Quicke of Kulin 12:50 – Michael Hogan of Bencubbin 13:00 – Ian Hall of Aldersyde
12:45 - 13:15	*GeoDesign for Sustainable Development* Tom Gardner	*Image Reconstruction in the Contour Domain* Dr. Gabriel Scarmana	*Bay OK - shining the spotlight on water* Gene Hardy	*Attending the Glacier Size Biases in Canada's Reference Glacier Mass Balance Observing System* Paola de Rose	*GIS-Based Spatial 3D Visual Highway Construction* Liwei Wang	*How do you provide simple-to-use geospatial workflows to non-GIS experts that are cost-effective and manageable* Anton van Wyk		
13:15 - 13:45	*Geospatial Visualisation in Place: new opportunities with augmented reality* Prof Mark Billinghurst	*Integrated Database Design* Sungjoo Lee	*Restoring Lake Ewlyamartup* Ella Maesepp	*A Trial of Landcover Change Carbon Accounting in Guangxi Province* Dr. P A Caccetta	*Strategic Planning - a new approach using modern technology* Alex Leith	*Spatial Data as a Service* Paul Tetley		
13:45 - 14:45	**Lunch** *sponsored by* ***Whelans***							
	The Social Impacts of the Changing World ***Riverside Theatre*** **Chair: Gerry Gannon**	**GIS and NRM** ***Riverview Rooms 4 & 5*** **Chair: Bruce Hamilton**	**NRM** ***Meeting Rooms 1 - 3*** **Chair: Marieke Jansen**	**ABCC Scientific Workshop** ***Meeting Room 6*** **Chair: Dr. Hilcea Ferreria**	**Digital Earth Technologies** ***Meeting Room 7*** **Chair: Mike Ridout**	**Spatial Data Infrastructure (SDI)** ***Meeting Room 8*** **Chair: Marty Stamatis**	**Workshop 1** ***Meeting Room 9***	**Workshop 2** ***Meeting Room 10***
14:45 - 15:15	*Social Impact Assessments of Major Development Projects* Andreas Sadler	*Remote Sensing of Intensively Managed Dairy Pastures of NZ* Dr. Rebecca Handcock	*Adaptive Management - developing IT to incorporate social science into environmental management auditing of small businesses (SMEs)* Paul Lock	*Landscape-Scale Monitoring and Modelling Applied in a Chinese Environment* Dr. Peter Caccetta	Keynote: Assoc. Prof. Dr. Temenoujka Bandrova *Multifunctional Cartographic Application of 3D Model*	*A-Spec.....What are the lessons for developing specifications?* George Havakis	*ANZLIC - OSDM Access and Discovery Tools* John Weaver and Margie Smith Office of Spatial Data Management	
15:15 - 15:45	*Citizen Science and the Environment* Piers Higgs	*Improvement of Land Cover Classification* A/ Prof. Linlin Ge	*Managing the Impacts of Peri-Urban Development* Stephen Farrell	*Land Cover Time Series from Long-Term Satellite Data Records* Rasim Latifovic	*On Geographical Thought and Research Methods Based on Digital Earth* Prof. Xinyuan Wang	*Growth While Maintaining the Integrity of the Network* Bob Schwartz		*WA Local Government GIS Workshop* Paul Jupp
15:45 - 16:15	*PGIS Supported Knowledge Based Participation/ Empowered Community Members* Dr. Mulalu Mulalu	*Prototyping the Visualisation of Geographic and Sensor Data* Dr. Petr Kubicek	*How do we get Women to the NRM Party?* Natarsha Woods	*Characterisation of Human Occupation Trajectories – Patterns in the Amazon through Data Mining* Dr. Hilcea Ferreria	*Immersive Technologies, Human Computer Interfaces and Digital Earth* David Wortley	*Managing Scheme Evolution in a Federated Spatial Database* Xiaoying Wu	IJDE Editorial Board Meeting Closed Session	
16:15 - 16:45	Keynote: Alison McGilvray *Managing WA's Western Deserts with the Traditional Owners*	*Three Gorges Project Eco-Environmental Information System* Bing-fang Wu	*Working with the Wine Industry on Improving Energy and Water Management* Keith Pekin	*Comparative Study of Urban Land Cover Change - Tianjin and Toronto* Dr. Li Xinwu	Keynote: Prof. Dr. Manfred Ehlers *An Empirical Case Study for the Importance of Mobile Webmapping*	*Opening up Enterprise GIS: a Web 2.0 spatial architecture* Brian Hope		
16:45 - 17:15	*Dynamic Visualisation of Tourism Impact* Prof. Geoff West	*TargetOn – facilitating and measuring on-ground action by farmers using collaborative Web 2.0 technologies* Ian Kininmonth	*Evaluation of the Effectiveness of the Blackberry Containment Zone, South West Western Australia* Andrew Reeves	*Forest Information Monitoring in Tasmania using Synthetic Aperture Radar Data* Prof. Tony Milne	*The Issue of Cloud Computing for Digital Earth* Dr. Yong Xue	*An SDI for Points of Interest* Peter Twiby		
19:00 - 23:00	**Gala Dinner** *sponsored by* ***Helping Hand*** ***Dinner Speakers: Fiona Milburn and Mark Schafer from WireFrame Inc., "Playing in the Foam"***							

** SSSI CPD Points for Day Two: 7.5 points*

DAY THREE: THURSDAY 25 AUGUST 2011

8:45 - 9:15	**Registration**							
9:15 - 9:25	**Welcome - MC** ***Riverside Theatre***							
	The Cloud Discussion ***Riverside Theatre*** **Chair: Gerry Gannon** **Co-Chair: Darren Mottolini**	**Health** ***Riverview Rooms 4 & 5*** **Chair: Narelle Mullan**	**Digital Earth: Emergency Management** ***Meeting Rooms 1 - 3*** **Chair: Prof. Dr. Milan Konecny**	**GIS and NRM** ***Meeting Room 6*** **Chair: Prof. Bert Veenendaal**	**NRM** ***Meeting Room 7*** **Chair: James Lush**	**Earth Visualisation** ***Meeting Room 8*** **Chair: Dr Alan Forghani**	**Workshop 1** ***Meeting Room 9***	**Workshop 2** ***Meeting Room 10***
9:30 - 10:00	**The Cloud Presentations and Panel Discussion** Roland Slee Oracle Matthew Coleman Google Earth Builder from an Ergon Energy Perspective co-presenting with Adrian Tout from Google Chaowei Yang George Mason University and CISC Dr. Sonny Tham, Amristar, The NBN, GIS and "the Cloud"	*Where, How Far and at What Speed?* Dr. Bryan Boruff	*How LI Helps in Responding to Natural Disasters* Ben Somerville	*Landsat Vegetation Trends and Land Management* Katherine Zdunic	WA Landcare Award Finalists' Presentations	*Temporal Earth: Visualising World History at all Timescales* Matt Coller		
10:00 - 10:30		*Tobacco Outlets: exacerbating tobacco-use disparities between socio-economic groups?* Dr. Grace Yun	*National Exposure Profile* Dr. Krishna Nadimpalli	*Island Trails: using GIS to tread carefully through the planning process* Shane Kearney		*Digital Earth and Advancements in Evidence Driven 3D Visualisation* Richard Simpson		
10:30 - 11:00		*Extending Health Web Mapping with Spatial Analytical Tools* Ishara Kotiah	*3D Laser Scanner to Detect Large Reservoir Landslide Displacement* Mowen Xie	*Spatial Analysis Drives Strategic Investment* Kylie Bishop		*Fresh Eyes to Old Problems: extending the digital realm through interdisciplinary and community cooperation* Dr. Felicity Morel-Ednie Brown		
11:00 - 11:30		**Prep time for WA Landcare Awards Gala Luncheon**	*Geospatial Related Activities After 3.11 Crisis in Japan* Prof. Hiromichi Fukui	*Managing Acid Sulphate Risk* Dr. Balbir Singh		*Using a Virtual Globe to Present National Geoscience Data* James Navin		
11:30 - 12:00				*An Integrated Approach to Controlling Weeds* Klaus Braun		*Presentation of Animal and Environmental Data* Prof. Dr. Manfred Ehlers		
12:00 - 13:00	**Lunch**							
	Rapid Fire Emerging Technologies ***Riverside Theatre*** **Chair: Gerry Gannon**		**Digital Earth: Emergency Management** ***Meeting Rooms 1 - 3*** **Chair: Prof. Dr. Milan Konecny**	**ABCC Scientific Workshop** ***Meeting Room 6*** **Chair: Paola de Rose**	**Monitoring Digital Earth** ***Meeting Room 7*** **Chair: Dr. Rebecca Handcock**	**GIS and Data Management** ***Meeting Room 8*** **Chair: Lisa Buckleton**	**Workshop 1** ***Meeting Room 9***	**Workshop 2** ***Meeting Room 10***
13:00 - 13:30	Keynote: Stuart McLean Head of Enterprise at Google Australia - New Zealand	***WA Landcare Awards Gala Luncheon (commences at 12:00)*** ***Riverview Rooms 4 & 5*** *PR NRM Vision and Challenges* Dr. Bruce Hamilton *Estimating the Environmental, Social and Economic Value of Native Bushland* Paul Hardisty	*What's New in the Crisis Management of the Czech Republic* Assoc. Prof. Josef Janosec	*The Global Forest Observation Initiative (GFOI)* Dr. Hilcea Ferreria	*Urban Monitor* Dr. Peter Caccetta	*Role of Spatial Information to Support a Major Policy in Water and Natural Resource Management in Australia* Dr. Alan Forghani	WireFrame Workshop Invitation Only	*Screening of 'Greener Horizons' – five wheatbelt farmers tell their tree crop stories.* Monica Durcan A different story every 10 minutes: 13:05 – Andrew and Suzi Sprigg of Bonnie Rock 13:15 – Kingsley Vaux of Ongerup 13:25 – Norm and Trudi Quicke of Kulin 13:35 – Michael Hogan of Bencubbin 13:45 – Ian Hall of Aldersyde
13:30 - 14:00	**Quick 10-minute updates** Fly in for a fly through of the most exciting, innovative and up-to-date technologies in your industry! Using GIS and Realtime 3D to Create Intelligent Interactive Models in Arup (Ben Cooper-Woolley) 3D GIS in the Age of Cloud Computing (Tamrat Belayneh) Make GIS Accessible to all Areas of Your Enterprise (Joseph McGehan) nearmap.com: past, present and future (Simon Cope) HyperWeb: large-scale image serving for the internet (Ben Last) Google: the new wave of distributing spatial information (Nathan Eaton)		*Soil Erosion Risk Assessment After Severe Bushfires Using RUSLE and MODIS* Dr Xihua Yang	*Case Study: Using the SISMADEN – Natural Disaster Monitoring and Alert System – in a Landslide event in Angra dos Reis, Brazi* Dr. Hilcea Ferreria	*Spatial Assessment of the Impact of Land Clearing on Water Balance Using Remote Sensing, GIS and 1-D Modeling in the Daly Catchment, NT* Dr Guy Boggs	*The Changing of the Guard* Ryan Fraser		
14:00 - 14:30			*Building a Spatial Information and Mapping System* Shane Conserdyne	Plans for Future ABCC Meetings	*Combined Analysis of Optical and SAR Remote Sensing Data for Forest Mapping and Monitoring* Dr. Eric Lehmann	*Streamlining Aboriginal Heritage Applications* Chris Dorrian		
14:30 - 15:00			*Volunteering your GIS Skills* Mark Taylor		*Vegetation Monitoring of Lake Toolibin using Landsat Satellite Imagery: analysis and implementation* Ricky van Dongen	*Diversity Across the Wheatbelt* Cliff Morris		
15:00 - 15:30	***WALIS 30th Anniversary Afternoon Tea***							
15:30 - 16:00	**Mike Bradford (Landgate), The Location Information Strategy for Western Australia** ***Riverside Theatre***							
16:00 - 16:30	**Conference Wrap-up** **Closing Ceremony (handover of flag)** ***Riverside Theatre***							
16:30 - 17:30	***Closing Function*** ***Riverside Theatre Foyer***							

* SSSI CPD Points for Day Three: 6 points

The conference program incorporated seven workshops. These were:

1. Getting Your Paper Published - an editor's view; A.P. Cracknell - University of Dundee, UK, sponsored by International Journal of Remote Sensing
2. Screening of 'Greener Horizons' – five wheatbelt farmers tell their tree crop stories, Monica Durcan
3. Digital Cities Working Group Workshop on Digital Cities Objectives, Richard Simpson
4. O-Spec and Prelude to BSpec, George Havakis
5. ANZLIC - OSDM Access and Discovery Tools, John Weaver and Margie Smith, Office of Spatial Data Management
6. WA Local Government GIS Workshop, Paul Jupp
7. WireFrame Workshop (invitation only)

Close of Conference

The official close of the conference began in the Riverside Theatre with an address by Mike Bradford from Landgate on the Location Information Strategy for Western Australia. This was followed by the conference wrap-up delivered by Dr Marnie Leybourne, former Director of WALIS and Damian Shepherd, current acting Director of WALIS.

Professor Guo Huadong then announced the hosts for the next ISDE Summit and 8th International Symposium on Digital Earth (ISDE8). Wellington, New Zealand won the bid to host the ISDE Summit in 2012 and Kuching in Sarawak, Malaysia was announced as the host of the 8th International Symposium on Digital Earth in 2013. The ISDE flag was passed from Perth to the Malaysian ISDE8 representatives as part of a spectacular aerial acrobatic display to close the Conference.

Conference Tours

Three conference tours took place on Monday, 22 August 2011 and Friday, 26 August 2011.

Supercomputers and Satellites; Monday 22 August, half day

The first stop for this tour was the iVEC facility in Kensington. iVEC provides supercomputing, data storage, scientific visualisation and eResearch services to researchers in Western Australia. The tour provide an overview of these services and their future, including iVEC's involvement with the proposed Square Kilometre Array (SKA) project, and finished with 3D visualisation of research projects from Western Australian researchers.

The tour then visited Landgate's Satellite Remote Sensing Services (SRSS) facility, which is co-located with CSIRO in Floreat. SRSS operates at the forefront of satellite technology both nationally and internationally. Satellite imagery products and services are used extensively by agricultural industries, rural planners, developers, exploration industries, environmental groups and government to assist in natural resource and land management.

Geothermal Energy, Seawater and Waves; Monday 22 August, full day

The geothermal tour showed visitors the sites and plans for the first two geothermal energy projects in Perth. The tour initially showed the preliminary test borehole and final site planned for the geothermal energy driven air conditioning project at the University of Western Australia. The group then visited the Pawsey Centre geothermal energy site and WA Geothermal Centre of Excellence (WAGCoE) at the CSIRO/ Curtin ARRC Building in Kensington. The visit to WAGCoE included a presentation on how spatial data is used for geothermal resource modelling.

The tour then travelled to the Perth Seawater Desalination Plant, which is run by the Water Corporation. The tour allowed visitors to see the seawater pump station, pre-treatment facilities, reverse osmosis building, potabilisation facilities, and the drinking water pump station.

Lunch was held at the Cockburn Wetlands Education Centre which promotes restoration activities, and environmental education of this local wetlands site.

The last visit was the Carnegie Wave Energy facility in Fremantle. Carnegie Wave Energy Limited are an Australian company focused on developing and commercialising the CETO wave technology to extract energy from ocean waves for the production of renewable, emission free electricity or potable water.

Applied Spatial Information in a Mining and Wastewater Management Context; Friday 26 August, full day

The tour travelled to the Kwinana Industrial Centre for a visit of the nutrient-stripping wetland established by CSBP for the treatment of on-site industrial wastewater prior to discharge to Cockburn Sound. This pilot wetland was an important part of the development of on-site wastewater management and was the first of its kind in Australia constructed to treat industrial wastewater.

The group then made a stop at the Beeliar Regional Park, which runs parallel to the coast through Melville, Cockburn and Kwinana. A highlight of this wetlands stop was the 'Welcome to Country' and story-telling by a local indigenous elder, followed by an interpretative walk of the lake and its environs. A bush-tucker lunch was taken at this site.

The group then made their way to the ALCOA Huntly bauxite mining operation which is located in the jarrah forest just 1.5 hours south-east from Perth. Alcoa's GIS manager demonstrated best practice use of spatial planning systems where participants saw excellent examples of daily use through to life of mine planning, as well as Alcoa's world class mining and rehabilitation operations.

Conference Dinner

The conference Dinner was held on Wednesday, 24 August at the Bellevue Ballroom within the Perth Convention and Exhibition Centre. Over 500 local, national and international guests attended the event.

On behalf of the International Journal for Digital Earth (IJDE), Professor Guo Huadong announced that Professor Alessandro Annoni from the EU Joint Research Center (JRC) would chair the IJDE Award Committee, for recognising quality contributions to IJDE.

The guest speakers for the evening were motion capture pioneers, Mark Schafer and Fiona Milburn from the Auckland-based computer animation company WireFrame Ltd. Wireframe described how 'spatial' relates to the motion capture and computer animation, including clips from several feature films for which WireFrame has provided expertise, including the Lord of the Rings trilogy and Rise of the Planet of the Apes.

The host for the evening was the Master of Ceremonies for ISDE7, Gerry Gannon. The sponsors for the Gala Dinner – The Helping Hand Group – organised a Silent Auction with the proceeds donated to the Make a Wish Foundation.

WA Landcare Awards Gala Luncheon

The WA Landcare Awards were held on Thursday, 25 August in the Riverview Room. Category finalists and colleagues joined together to enjoy lunch and celebrate the 2011 winners of the awards. James Lush from ABC radio was the Master of Ceremonies for the luncheon.

The Governor of Western Australia and Patron of Landcare Western Australia, Mr Malcolm McCusker, announced the winners.

Committees and Support

The Organising Committees for the conference comprised of:

Strategic Organising Committee

- Dr Marnie Leybourne (Conference Convenor), WALIS Office
- Damian Shepherd (Conference Convenor) WALIS Office
- Pamela Watson (Joint Conference Coordinator), WALIS Office
- Melissah Johnston (Joint Conference Coordinator), WALIS Office
- Marion Gilbert (Assistant Conference Coordinator), WALIS Office
- Ian Hyde (General Manager), Landgate
- Arnold Wong (International Services), Landgate
- Robin Piesse (Manager Market Development), Landgate
- Nikki Joyce (Media & Public Relations Officer), Landgate
- Changlin Wang (ISDE representative), Chinese Academy of Science
- Linlin Ge (ISDE representative), University of NSW
- Peter Woodgate (ISDE representative), CRC for Spatial Information
- Tom Gardner (Business Development), Esri Australia
- Michael Ridout, CRC for Spatial Information
- David Hocking (Chief Executive Officer), SIBA
- Linda Soteriou (General Manager) Perth Region NRM
- Rob Freeth, Freeth Consulting

Operational Committee

- Dr Marnie Leybourne (Conference Convenor), WALIS Office
- Damian Shepherd (Conference Convenor) WALIS Office
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- Stephen Bandy (WALIS Councillor), Geological Survey of Western Australia
- Phil Houweling (Teachers representative), John Calvin Christian School
- Tom Gardner (Business Development), Esri Australia
- Natalie Moore, Department of Agriculture and Food
- Carolyn Jenour, Perth Region NRM
- Erin Devlin, Perth Region NRM
- Darren Mottolini, Landgate

The conference secretariat was International Conferences and Events (ICE) Pty Ltd and the graphic design was undertaken by Dillon Graphics.

Next Summit and Symposium

The next ISDE Summit will be held in Wellington, New Zealand in 2012 and the 8th International Symposium on Digital Earth (ISDE8) will be held in Kuching, Sarawak, Malaysia.

Damian Shepherd
A/ Director, WALIS
March 2012

Peer Review Paper Process and Scientific Committee

The conference provided an opportunity for authors from a wide range of disciplines to submit papers for peer review, non peer reviewed oral presentations and the poster session. The role of the Scientific Committee was to review the draft program set by the abstract review group, select appropriate reviewers for papers and posters requiring peer review and, on receipt of the reviewers' comments, finalise the event program.

Papers submitted for peer review were assessed by the scientific committee and other nominated researchers (see list below).

A total of 326 abstracts were submitted and 176 accepted. 99 papers were chosen by their authors to be non peer reviewed. Of the 77 papers submitted for peer review, 37 were accepted, resulting in an acceptance rate of 48%.

The Scientific Committee was chaired by Dr Linlin Ge and included a range of experts covering the key topic areas of the conference.

The ISDE7 Organising Committee would like to thank the Scientific Committee members and associates for their time and the effort involved in peer reviewing the papers for the ISDE7 Conference.

Dr Linlin Ge	Professor, School of Surveying and Spatial Information Systems, University of New South Wales
Professor Changlin Wang	Secretariat Director, International Society for Digital Earth
Dr Peter Woodgate	CEO, Australian Cooperative Research Centre for Spatial Information; Member of ISDE Executive Council
Professor John van Genderen	Faculty of Geoinformation Science and Earth Observation, University of Twente, The Netherlands
Dr Phil Collier	Research Director, Australian Cooperative Research Centre for Spatial Information
Professor Peter Teunissen	ARC Federation Research Fellow, Department of Spatial Sciences, Curtin University of Technology
Dr Renee Bartolo	Program Leader, CSIRO; Chair, SSSI Remote Sensing Commission
Dr Alan Forghani	Director, Natural Resources Information, Murray Darling Basin Commission
Professor Bert Veenendaal	Head of the Department of Spatial Sciences, Curtin University of Technology
Professor Geoff West	Professor of Spatial Information, Curtin University of Technology

Professor Abbas Rajabifard	Director, Centre for Spatial Data Infrastructures, University of Melbourne
Professor Stuart Phinn	Director, TERN, University of Queensland
Professor Graeme Wright	Associate Dean, Curtin University of Technology Editor-in-Chief, Journal of Spatial Sciences
Dr Bruce Hamilton	Deputy Chair, Perth Region NRM
Dr Marnie Leybourne	Director, Western Australian Land Information System (WALIS)
Professor Armin Gruen	Institute of Conservation and Building Research, ETH Zuerich
Mike Ridout	CRC-SI
Professor Anthony Lewis	Louisiana State University, USA

The compliant peer reviewed papers are detailed below, listed alphabetically according to the lead author's surname.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

Comparison of relative radiometric normalisation methods using pseudo invariant features and SPOT imagery

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ABSTRACT

Relative radiometric normalization (RRN) is used to remove the effects of solar illumination conditions, atmospheric scattering and atmospheric absorption on at-sensor radiance values. The choice of RRN method will affect the success of land cover change detection using multi-temporal satellite data. This study compares two RRN methods using pseudo-invariant features (PIFs). The PIFs are radiometric ground control points at which little or no change occurs between different time periods. It is therefore assumed that differences in radiance values between time periods are the result of inconsistencies in acquisition conditions. Traditionally, PIFs are subjectively chosen by the analyst based on known objects, often man-made, that should not change over time. An alternative objective method of selecting PIFs uses a principal component analysis to identify the PIFs. This method is well suited to remote areas where man-made objects are not available making manual PIF identification difficult. The performance of both methods was compared using two sets of cloud and haze free SPOT data. The difference between the results of radiometric normalisation between two methods, where compared using the root mean square error (RMSE) and normalised differenced vegetation index (NDVI). The RMSE errors were lower for the automatic PIFs selection method comparing manual PIFs selection. In the application of NDVI difference 2007-2010, automatic PIFs selection method can reduce the difference of two images while retaining radiometric resolution. In conclusion, manual selection of PIFs is subjective and introduces observer bias. Automatic PIF selection methods can overcome these issues, and provide improved relative radiometric normalization in remote semi-arid environments.

1 INTRODUCTION

To perform multi-temporal remote sensing it is important to address variations in solar illumination conditions, atmospheric scattering and atmospheric absorption that create differences in the at-sensor radiance values unrelated to land surface reflectance [1-3]. Radiometric correction is required to remove these artefacts. Radiometric correction comes in two forms, absolute or relative [4]. Choosing the correct relative radiometric normalisation (RRN) method is crucial to successfully description of land use change when using remote sensing time-series.

The basic principle of RRN is to rectify the digital numbers (DN) of multi-temporal images band by band to a reference image. A common method of RRN utilises pseudo-invariant features (PIFs) [5]. Traditionally, PIF selection uses man-made elements such as large roof tops and roads often in urban and/or industrial areas that are selected manually. This method has been used in many studies for land change detection and classification [2, 6-8]. Although, manual selection of invariant features has been successfully employed in the studies mentioned above it has limited application in remote areas, which often do not contain manmade PIFs [9]. Furthermore, the selection of PIFs can be a time consuming process also affected by the subjectivity of an analysts interpretation [10]. To address the issue of PIF selection, many researchers have focused on improving the PIFs selection methods. Mostly using statistical models to control and improve the quality of PIFs through automatic selection, such as Kauth-Thomas transformation [11], scattergram-controlled regression [12], principal component analysis (PCA) [13], 3D PCA [14], and wavelet transformation [15]. The advantages of these automatic methods are: i) an increase in the total number of PIFs; ii) reduction in human intervention and subjectivity; and iii) reduction in cloud / shadow / snow effects. Additionally, using Du et al's [13] PCA method, there will not be a loss of radiometric resolution.

In this study, both automatic PIF selection using a modified version of Du et al's [13] PCA and traditional manual PIFs selection methods are compared using a common set of SPOT (Satellite Pour l'Observation de la Terre) 5 images of remote arid zone environments. The performance of the two methods is quantitatively assessed, and the disadvantages and advantage of the PIFs selection methods are discussed.

2 DATA AND METHOD

Two SPOT 5 datasets were used to compare PIF selection methods. SPOT 5 level 1A data were acquired on 20th October 2007 and 21th October 2010. These cloud free sets were centred on the Kidston Gold Mine site in north Queensland, Australia. Surrounding the mine are areas of natural vegetation and pasture. The 2007 image was used as the normalisation reference image and the 2010 image was used as the normalisation target or warp image. The warp image was geometrically registered to the reference image using nearest neighbour sampling with ± 1 pixel mean squared error, and then subset to a common area with extent of 1467*1606 pixels.

2.1 PIFs selection method for normalization

In this study, the automatic PCA PIF selection method was scripted in ENVI/IDL 4.7 (ITT Visual Information Solutions). PCA [16] is a common technique used in multivariate statistics to convert a set of observed variables to a set of linear combined variables that account for the variance within the data. When applied to radiometric correction, PCA uses pixel values from band pairs in both images with the pixels from the reference and the warp image treated as variables.

This method assumes that if two images of the same area are compared in the absence of significant land cover change, linear effects will result in a scatter plot pattern with an elliptical shape. Land cover change is represented by pixels that are found outside of the elliptical distribution while changes that result from atmospheric effects result in a slope that deviates from unity. The aim of relative radiometric normalisation is to retain real land cover change information using appropriate PIFs at which ‘’no change” occurs. The goal of normalisation is to achieve a slope close to 1. Only pixels that show little or no deviation from the major axis will be suitable candidates for PIFs. Using this method, PIFs are developed independently for each band. There are five steps in the selection of PIFs for each band i) PCA is applied to the processed images pairs of each same band ii) candidate PIFs are selected from pixels which fall perpendicular to the major axis at a range of ± *l ,*which is threshold in minor axis for selecting PIFs candidates . iii) For each *l* value the correlation coefficient (*r*) is calculated and the candidate PIFs are chosen from the range *l* with the highest correlation value, iv) gains and offsets are calculated with the candidate pixels using regression method, and v) the calculated gains and offsets are used to transform the slope of the PIFs in the warp image so that the slope approaches unity.

The traditional PIF selection method was conducted by manually selecting PIFs in both acquisitions to calculate the slope and offset for each band. Then, using a linear transformation the warp image is radiometricly corrected. The manually selected PIFs have approximately the same elevation as the other areas in the scene with large extents for easy identification [17].

2.2 Accuracy assessment for normalization

We assessed normalisation results in both methods using root mean square error (RMSE) and NDVI. RMSE is a frequently-used statistical measure of the accuracy of values predicted by a model or an estimator [18]. It has been used in previous remote sensing studies to test the success of normalisation [5]. RMSE was used to measure the statistical agreement of a normalized image with the reference image [4] using the follows formula:

$$RMSE_K = \sqrt{\frac{\sum (W_K - R_K)^2}{n}} \qquad (1)$$

K is the band number for the warp image (W) and reference image (R), W_K is the digital number of warp image in band K, R_K is the digital number of reference image in band K, n is the total number of pixels in the scene. Lower values of RMSE indicate better fit and thus a better normalisation result.

RRN method can reduce the difference between two images, how different RRN methods will affect the degree of change that may be detected , Land cover change detection is reasonable way to assess the normalisation accuracy[14].NDVI is calculated from the red portion of the visible and near-infrared (NIR) radiation (NIR-RED)/ (NIR+RED)[19]. This method provides meaningful comparisons of seasonal and inter-annual changes in vegetation growth and activity [20] and has been used to test the success of normalisation [3, 21].

3 RESULT AND ANALYSIS

The SPOT images were radiometrically normalized with the gains and offsets calculated using the two PIF selection methods (Table 1). In this study area, the main land use is pasture and historic mining, so man-made features of appropriate size that can be used as PIFs. As a result only 12 features were found using manual PIF selection. This included roads with a 50-100m width which were easy to identify in the SPOT 10m image and a reservoir located to the north of mine sites. For automatic PIF selection method, over 100 PIFs were selected. The *r* values show that the strength of the relationship between the reference and warp images was higher for the automatic method than for manual PIFs method. The greatest differences in *r* values were in band 3, with the manual method having a value of 0.88 compared to 0.99 for the automatic method.

Table 1 Gains, offsets, and *r* value for radiometric normalization for automatic and manual PIF selection methods

	Automatic PIFs selection method				Manual PIFs selection method			
	Gain	Offset	r	Num of PIFs	Gain	Offset	r	Num of PIFs
Band1	0.874	22.01	1.00	131	0.41	37.35	0.96	12
Band2	1.10	-11.45	0.99	189	0.55	45.81	0.95	12
Band3	1.32	-29.00	0.99	102	0.62	83.56	0.88	12
Band4	1.67	-67.70	1.00	134	0.88	31.72	0.92	12

RMSE was calculated for each band and selection method and for comparison purposes, the RMSE of the raw image data without any radiometric normalisation were also calculated (Fig.1). As shown in Fig.1, both methods have lower RMSE values than the raw images. For example in band 1, the RMSE value from raw image is 36.48. In contrast, both RRN methods had lower RMSE value with a value of 7.42 for the automatic method and 11.32 for manual method. The RMSE of the manual method was higher than that from automatic method for 3 out of the 4 bands. In the case of band 4 the manual method had a lower value than the automatic method. The difference, however, was small, approximately 0.76. The difference between PIF methods was highest in band 3, with the manual method having a RMSE value of almost double that of the automatic method. Band3 (0.78-0.89µm) with 10m resolution is associated with the vegetation type and condition [22]. The infrared band is sensitive for vegetation detection, thus, in this study area, some variations in vegetation growing conditions might be the cause of higher RMSE in this band.

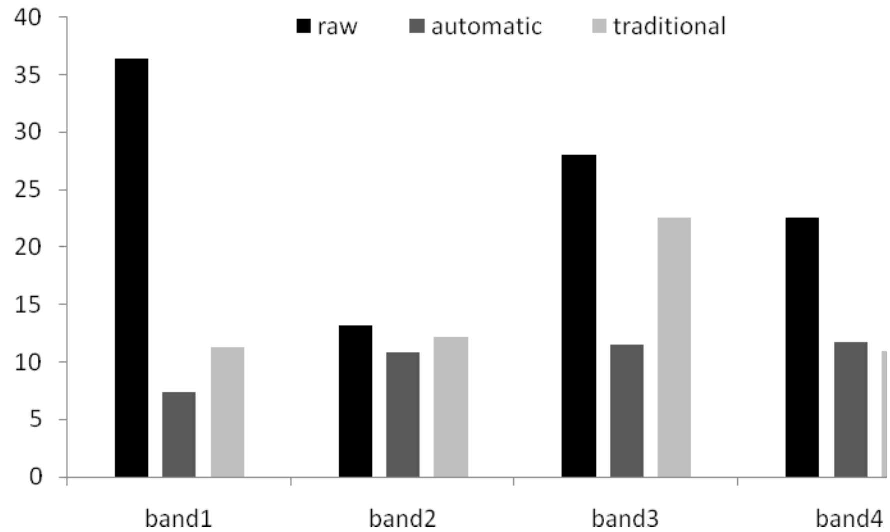

Figure 1: Comparison of RMSE for normalized images using by different PIF selection methods. The y axis is RMSE value calculated band by band, between reference image and raw image: without normalization, normalised using an automatic PIFs selection method and normalised using the manual PIFs selection method.

NDVI images (Fig. 2) were generated using band 3 and band 4 from the reference image and change between 2007 and 2010 was calculated. The image of 2007 and image of 2010 were both captured in October, which is dry season in Australia. Therefore, it was assumed that there is very little change between 2007 and 2010 in this rural area, thus most change between dates is predominately the result of radiometric effects. Fig. 2 shows that the automatic PIFs method can reduce the amount of difference between years measured using NDVI compared to the un-normalised image and the image normalised using manual PIF selection method.

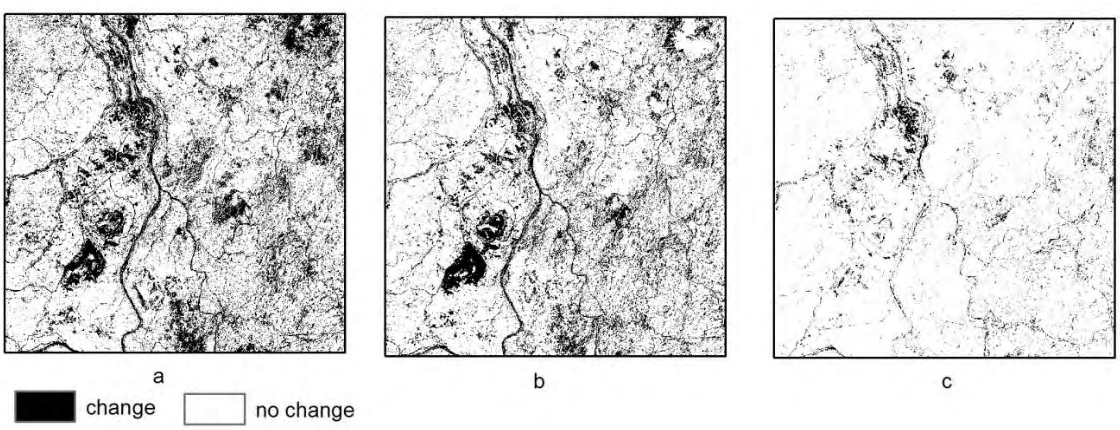

Figure2: NDVI difference 2007-2008. a) NDVI change detection between reference image and raw image without normalization. b) Change detection difference using traditional manual method. c) Change detection using automatic method.

4 DISCUSSIONS AND CONCLUSION

The results of the evaluation of the two different radiometric normalisation methods, as applied to the SPOT data in Australia, have shown that both methods can reduce the impact of atmospheric and sensor effects in comparison to unnormalised data. The method presented in this research is a modification of Du et al’s [13] PCA RRN method for selecting PIFs. The assessment of normalisation quality using both RMSE and change detection in NDVI found that the automatic PIFs selection method can reduce more change, and perform better in normalisation. However, we still need ground truthing to assess the accuracy of NDVI result after normalized by both methods.The application of manual PIFs selection method is simpler than the automatic PIFs selection method, and only requires the selection of PIF pixels in two images to calculate gains and offsets. The lack of man-made objects in this remote area, however, limited manual PIF selection to 12 targets compared to more than 100 for each band using the automatic method. The small number of PIFs used in the manual selection method is likely to result in a low accuracy normalisation. The automatic PIFs selection provides a repeatable and objective method, and has a potentially higher accuracy in remote areas where constructed features are rare. Furthermore, for larger datasets the automatic PIFs method can be used programmatically and thus is more efficient than manual methods. The drawbacks of the automatic PIF selection method include the assumption that the relationship between PIFs in different images is linear which may be inconsistent with the basic principle PIF selection using the traditional method [23]. Further PIFs selected were not the same in each band indicating that the PIFs chosen are not truly invariant [14].

In conclusion, manual PIFs selection is subjective and introduces observer bias to the selection of PIFs and in remote areas observer selected PIFs may be sparsely available. Automatic PIFs selection method can overcome these issues. Further study is needed to develop generalisations that describe suitable and appropriate conditions for each method quantifying their performance for a range of practical applications.

ACKNOWLEDGEMENT

We would like to thank SPOT imagery and particularly Rob Lees for the provision of the SPOT time-series data used in this study.

REFERENCE

[1] John R, J., in: K. C.Clarke (Ed.) Introductory Digital Image Processing, Person Prentice Hall, 2005, pp. 203-213.
[2] Coppin, P.R., M.E. Bauer. Processing of multitemporal landsat tm imagery to optimize extraction of forest cover change features, ieee trans. geosci. remote sensing, 32 (1994) 918-927.
[3] Song, C., C.E. Woodcock, K.C. Seto, M.P. Lenney, S.A. Macomber, Classification and change detection using Landsat TM data: when and how to correct atmospheric effects?, Remote Sensing of Environment, 75 (2001) 230-244.
[4] Yang, X.J., C.P. Lo, Relative radiometric normalization performance for change detection from multi-date satellite images, Photogramm. Eng. Remote Sens., 66 (2000) 967-980.

[5] Schott, J.R., C. Salvaggio, W.J. Volchok, Radiometric scene normalization using pseudoinvariant features, Remote Sensing of Environment, 26 (1988) 1-14, IN11, 15-16.
[6] Lenney, M.P., C.E. Woodcock, J.B. Collins, H. Hamdi, The status of agricultural lands in Egypt: The use of multitemporal NDVI features derived from Landsat TM, Remote Sensing of Environment, 56 (1996) 8-20.
[7] Hadjimitsis, D.G., C.R.I. Clayton, A. Retalis, The use of selected pseudo-invariant targets for the application of atmospheric correction in multi-temporal studies using satellite remotely sensed imagery, Int. J. Appl. Earth Obs. Geoinf., 11 (2009) 192-200.
[8] Geoffrey M. Henebrya, H.S., Using landscape trajectories to assess the effects of radiometric rectification
, Int. J. Remote Sens., 14 (1993) 2414-2413.
[9] Olthof, I., D. Pouliot, R. Fernandes, R. Latifovic, Landsat-7 ETM+ radiometric normalization comparison for northern mapping applications, Remote Sensing of Environment, 95 (2005) 388-398.
[10] Schroeder, T.A., W.B. Cohen, C. Song, M.J. Canty, Z. Yang, Radiometric correction of multi-temporal Landsat data for characterization of early successional forest patterns in western Oregon, Remote Sensing of Environment, 103 (2006) 16-26.
[11] Hall, F.G., D.E. Strebel, J.E. Nickeson, S.J. Goetz. Radiometric rectification - toward a common radiometric response among multidate, multisensor images
, Remote Sensing of Environment, 35 (1991) 11-27.
[12] Elvidge, C.D., D. Yuan, R.D. Weerackoon, R.S. Lunetta, Relative radiometric normalization of landsat multispectral scanner (mss) data using an automatic scattergram-controlled regression, photogramm. eng. remote sens., 61 (1995) 1255-1260.
[13] Du, Y., P.M. Teillet, J. Cihlar, Radiometric normalization of multitemporal high-resolution satellite images with quality control for land cover change detection, Remote Sensing of Environment, 82 (2002) 123-134.
[14] Paolini, L., F. Grings, J.A. Sobrino, J.C.J. Munoz, H. Karszenbaum, Radiometric correction effects in Landsat multi-date/multi-sensor change detection studies, Int. J. Remote Sens., 27 (2006) 685-704.
[15] Xing, Y., Q.G. Jiang, Z.P. Qiao, W.Q. Li, Study of Relative Radiometric Normalization Based on Multitemporal ASTER Images, in: Y. Wu (Ed.) Progress in Measurement and Testing, Pts 1 and 2, Trans Tech Publications Ltd, Stafa-Zurich, 2010, pp. 190-194.
[16] Pearson, K., On lines and planes of closest fit to systems of points in space, Philos. Mag., 2 (1901) 559-572.
[17] Jensen, J.R., Radiometric correction in: Introductory digital image processing : a remote sensing perspective entice Hall, 2005, pp. 344.
[18] Sweet, S., K. Grace-Martin, Data analysis with spass, Pearson Education, 2008.
[19] Tucker, C.J.,Red and photographic infrared linear combinations for monitoring vegetation
, Remote Sensing of Environment, 8 (1979) 127-150.
[20] Brown, M.E., J.E. Pinzon, K. Didan, J.T. Morisette, C.J. Tucker, Evaluation of the consistency of long-term NDVI time series derived from AVHRR, SPOT-Vegetation, SeaWiFS, MODIS, and Landsat ETM+ sensors, IEEE Trans. Geosci. Remote Sensing, 44 (2006) 1787-1793.
[21] El Hajj, M., A. Begue, B. Lafrance, O. Hagolle, G. Dedieu, M. Rumeau, Relative radiometric normalization and atmospheric correction of a SPOT 5 time series, Sensors, 8 (2008) 2774-2791.
[22] M.Lillesand, T., R.W. Kiefer, J. W.Chipman, Remote sensing and image interpretation, LCC, US, 2007.
[23] Jensen, J.R., Introductory digital image processing : a remote sensing perspective 2005.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

SPATIAL ANALYSIS DRIVES STRATEGIC INVESTMENT IN THE STOKES INLET CATCHMENT

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John Simons, Hydrologist, Department of Agriculture and Food Western Australia
David Ford, Esperance Regional Forum

ABSTRACT

Stokes Inlet, a normally closed estuary, lies on south coast Western Australia. It is fed by two tributaries (Young and Lort) with a combined catchment of over 500,000 hectares, with agriculture the major land use (280,000 ha). It has high environmental, social and cultural values, known by traditional custodians as Benwenerup.

Catchment practices can threaten inlet health, with sedimentation the primary threat. Investigations show deposition rates are around 10 times pre-European settlement rates [1]. Sediment cores from the inlet show two distinct layers of sediments from storms approximately 10 years (1999) and 40 years (1967/70) ago, indicating erosion is episodic.

Tracking the source of existing sediment within the inlet is not a high priority for investment; rather the priority is to identify areas where erosion can be prevented, thereby reducing the amount of sediment entering the inlet in episodic events.

To achieve this, a catchment water erosion hazard assessment was compiled by Department of Agriculture and Food WA for South Coast NRM and Esperance Regional Forum to determine spatial distribution of areas impacted by water erosion and characterise sedimentation processes. Aerial photography, field data collection and statistical modelling were used to map hillslope and channel water erosion hazard areas across the entire catchment [2].

This project has highlighted very little active erosion within the catchment, but has identified key areas that under the right conditions could contribute large sediment loads into tributaries. These priority areas will be used to design programs to improve knowledge and skills around water erosion hazard and land management.

1. BACKGROUND

Stokes Inlet is a normally closed estuary on the south coast Western Australia, west of Esperance (Figure 1). It is fed by two tributaries (Young and Lort rivers) with a combined catchment of over

500,000 hectares. The Inlet itself covers 14 square kilometres and is the largest sheltered body of water in the area and is within the Stokes National Park.

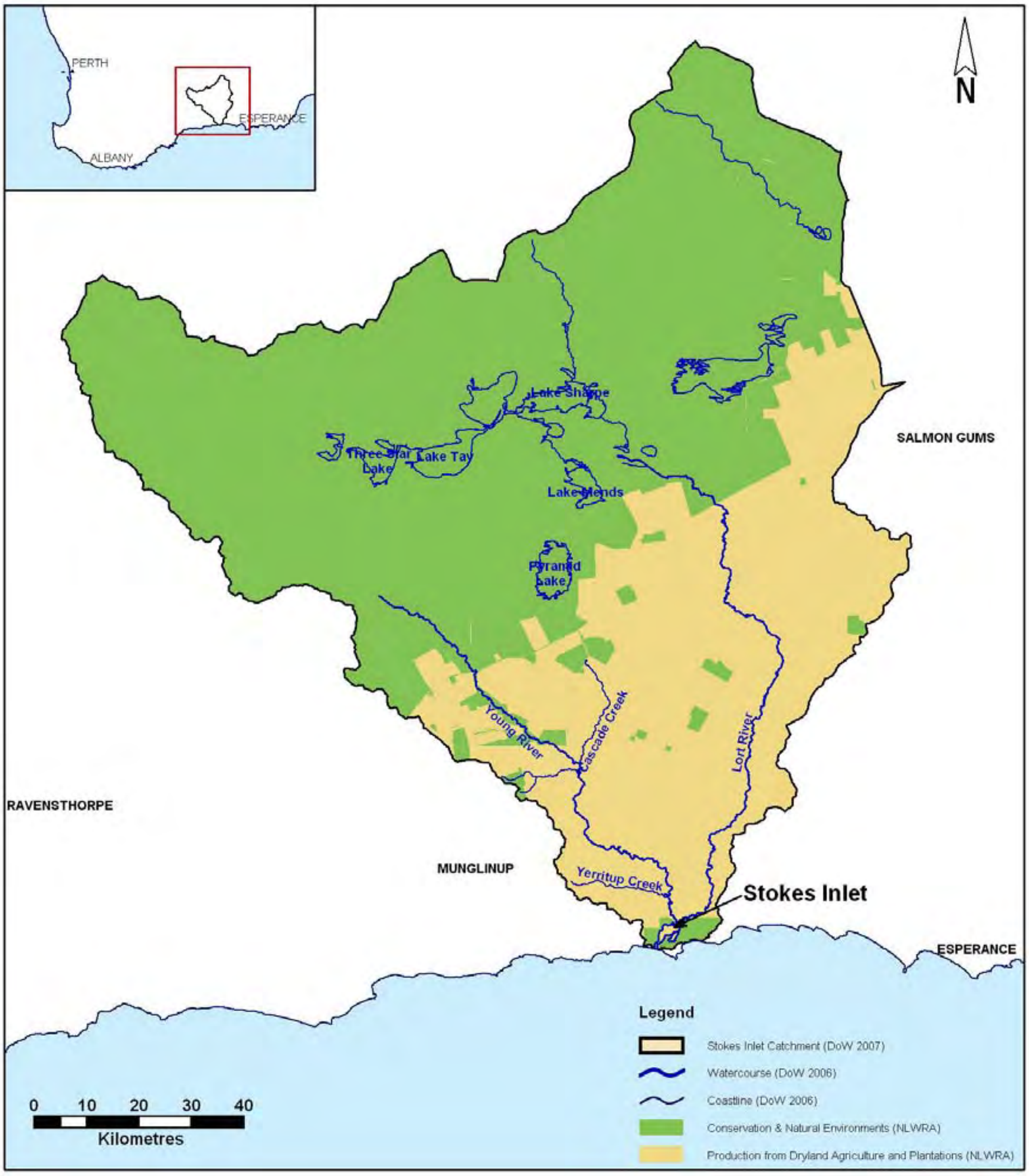

Figure 1: Stokes Inlet and its catchment

Agriculture is the major land use (280,000 ha), with catchment clearing taking place mostly between the 1950s and 1970s. Other economic values include commercial and recreational fishing, with the Inlet being one of the 13 inlets that make up the South Coast Estuarine Fishery. Recreational fishing is also highly popular, with an estimated 3440 fisher hours spent over a 12 month period [3].

The surrounding catchment also has high environmental values, with high biodiversity assets identified in the upper Lort and lower Young river corridors [3]. This includes the river corridors that provide a valuable link between the coastal strip and the Great Western Woodlands in the north.

Culturally, the area also has high importance and is known by the traditional custodians as Benwenerup.

The Stokes Inlet Catchment was first identified as a priority catchment by South Coast NRM as part of the National Action Plan for Salinity and Water Quality. In line with this, the Department of Water developed a management plan for the area in 2008 using a multiagency and community approach to look at threats and opportunities.

Consultation at this time identified the three biggest threats to the inlet as increasing population pressure, catchment impacts and commercial fishing. Population pressure is already managed through ensuring facilities and visitor access points are appropriate and pose a minimal risk to values. Commercial fishing is managed by the Department of Fisheries and is considered to be sustainable, with commercial yields showing no decrease since 1975 [3].

Sedimentation was identified as the primary threatening catchment practice. It is a concern because with the inlet basin and river pools shallowing or even filling, important habitat for plants and animals is lost and vegetation smothered. Geoscience Australia examined deposition rates within the inlet and found that deposition rates in the inlet are around 10 times pre-European settlement rates [1]. Sediment cores from within the inlet show two distinct layers of sediments from storms approximately 10 years (1999) and 40 years (1967/70) ago [1], indicating erosion is episodic. Tracking the source of existing sediment within the inlet is not a high priority for investment; rather the priority is to identify areas where erosion can be prevented, thereby reducing the amount of sediment entering the inlet in episodic events.

To achieve this, a catchment water erosion hazard assessment was compiled by Department of Agriculture and Food WA to determine spatial distribution of areas impacted by water erosion and characterise sedimentation processes. Aerial photography, field data collection and statistical modelling were used to map hillslope and channel water erosion hazard areas across the entire catchment [2].

2. WHERE TO START?

The greatest challenge when dealing with catchment scale issues is to know where best to target investment to achieve the desired outcome. It is never going to be economically feasible to complete an action across an entire catchment, particularly one as large as the Stokes Inlet catchment. It is also much more cost effective to address threats before they become an issue, rather than just patching up areas where erosion has already occurred.

However, to achieve this blend of actions, managers need to know where best to target efforts. Geographic information systems and spatial analysis can provide managers with the graphical tools required to prioritise activities across a broad scale. Spatial analyses can also be useful at the property level, and inform land managers about the potential problem areas within their property.

2.1. Catchment water erosion hazard assessment

The Department of Agriculture and Food WA undertook a study for Esperance Regional Forum and South Coast NRM Inc. to document the current spatial distribution of areas impacted by erosion and characterise sedimentation processes in the Lort and Young rivers catchment that feeds Stokes Inlet [2].

Aerial photography, field data collection and statistical modelling were used to map hillslope and channel water erosion hazard areas across the entire catchment [2]. Relevant spatially referenced environmental datasets (eg. soil erodability, soil-landscape units, remnant vegetation, streamlines, Digital Elevation Model (DEM), aerial photography (pre and post 2007), gamma radiometrics (K, Th, U channels) and average annual rainfall 1976 – 2007) were assembled for erosion analysis and modelling. The hydrologically corrected 30-m Digital Elevation Model (DEM) was used as input for terrain analysis, and a variety of datasets were produced to assist in defining areas prone to water erosion. Multiple models were trialled; the final models selected were constructed using a classification tree modified to reflect field observations. The final classification tree developed for hillslope erosion indicated slope-length factor dominates the prediction, with additional input from four other variables: flow accumulation, distance to stream, valley bottom flatness (MrVBF), and soil-landscape zone (sandplain).

Ground-truthing highlighted very little active erosion within the catchment, but has identified key areas that under the right conditions could contribute large sediment loads into tributaries. These priority areas will be used to design programs to improve knowledge and skills around erosion hazard and land management.

The assessment process found that the dominant erosion type within the catchment was gullying. In this case, “gully” refers not only to deeply incised channels, but includes a range of erosive channelised flow with associated sedimentation. Of the 311 total sites recorded as eroded, 10% were in river channels, 70% were gullies, 12% were sheet erosion, and 7% were a result of wind erosion. Almost all of the wind erosion sites were in the Mallee region, although there is considerable wind erosion close to the coastline as well. The vast majority of water erosion (94%) occurred on the sandplain, with the highest risk landscape positions being the flow lines that extend from the present stream network, where water naturally accumulates.

Across all sites, 78% showed recent erosion attributed to the 2007 storm, while 22% appeared to have erosional scars from prior storm events. Hillslope erosion information, when combined with stream erosion hazard provides an overall water erosion hazard map for the catchment (Figure 2). This hazard map provides managers with a tool for prioritising on-ground activities to reduce the potential for water erosion within the catchment.

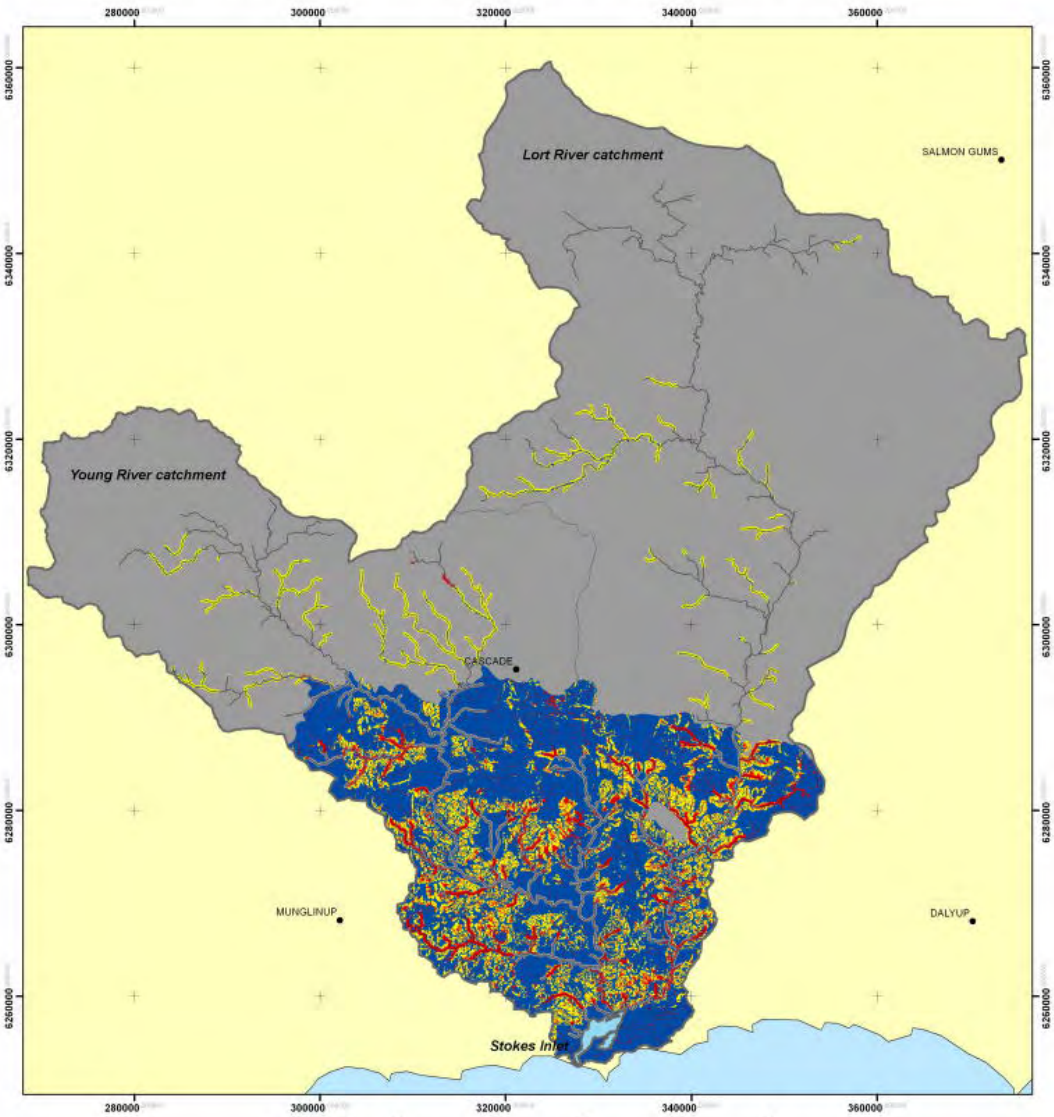

Figure 2: Hillslope and streamline water erosion hazard map for the Stokes Inlet Catchment (source [2]).

3. WHAT NEXT?

As highlighted above, the overall erosion hazard map for the Stokes Inlet Catchment provides a valuable tool for informing where on-ground works are needed to reduce the threat of erosion. Now that the tool has been developed, the next step is to communicate the results to land managers and follow up opportunities where we can co-invest to reduce the risk of erosion.

An erosion extension strategy has been implemented to communicate the results at a property level. Property maps illustrating the water erosion hazard areas, a summary of how the water erosion hazard assessment have been developed, a description of management options for specific hazard areas and follow up technical support was provided to all landholders with ‘high’ erosional hazard areas on the properties.

The development of the tool and extension of the results are really just the first steps in the process. The tool also provides managers with the ability to invest strategically and concentrate effort where investment is the highest priority. Along with targeting investment, the tool can be used to prioritise between sites using an equitable and defensible methodology.

In conclusion, before engaging in any catchment management exercise it is important to identify the values (in this case the Stokes Inlet), evaluate all the threats, and then assess the responsiveness to potential activities. It is important when trying to make a difference on a landscape scale that it is achievable and that there is sufficient evidence to support the approach.

The final step is to take the results out to land managers to evaluate their response to the required activities. With a tool that is underpinned by sound science, it is possible to demonstrate with evidence based decision making where on farm investment is required for off farm benefit.

REFERENCES

[1] Murray, E., Haese, R., Grosjean, E., Macphail, M., and Hancock, G. 2008. Historic environmental changes and present-day nutrient release from sediments in Stokes Inlet and Wellstead Estuary, south-western Australia. Geoscience Australia Record 2008/22, Commonwealth Government, Canberra, 52pp.

[2] K. Holmes, J. Simons, B. Marillier, N. Callow and P. Galloway. 2010. Water erosion hazard assessment of the Lort and Young Rivers catchment. Resource Management Technical Report 363. Department of Agriculture and Food Western Australia.

[3] Department of Water. 2008. Benewenerup: A management plan for the Stokes Inlet. Government of Western Australia.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

WHERE, HOW FAR, AND AT WHAT SPEED? THE USE OF GEOSPATIAL TECHNOLOGIES IN MEASURING AND CHARACTERIZING PHYSICAL ACTIVITY IN BEHAVIORAL HEALTH RESEARCH

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ABSTRACT

A large and evolving body of literature is concerned with influences of the built environment on physical activity. Geospatial technologies have become standard tools for developing measures of the built environment; however information on types, duration and location of physical activity have primarily relied on self-reporting by study participants. Whilst self-reporting provides a valuable starting point, errors in under and over reporting and geographic inaccuracies can propagate through the analytical process impacting statistical relationships. Advances in GPS technology however, offer a solution for this dilemma by providing an objective measure of people's movement through the built environment.

This paper will first present an overview of the current state of research coupling human GPS tracking data and GIS technologies for examining influences of the built environment on physical activity. Methods addressed will include identifying tracks from GPS points, linking GPS and accelerometer data and the classification of trips. Next a case study will provide an example of how these technologies were used to examine exposure to land use on walking trips in a sample of elderly adults across the Perth metropolitan area. Finally, the implications that GPS tracking data have on redefining how neighborhoods are spatially delineated for relating measures of the built environment to physical activity will be discussed. In conclusion, this paper highlights new opportunities in behavioral health research for using coupled geospatial technologies in measuring the built environment and its relation to physical activity.

Acknowledgement: the analysis in this paper was supported in part through collaboration with the PALMS Project (UCSD-Palms-Project.wikispaces.com) at the University of California, San Diego. Funded by NIH/NCI Grant 1 U01 CA130771.

1. INTRODUCTION

The influence of the built environment on healthy behaviors has received significant attention in the past decade and research in this field is growing rapidly [1, 2]. The built environment, which includes land use patterns, transportation systems, and design features, has the potential to facilitate physical activity, particularly walking behaviors, thus reducing risks to both chronic disease and obesity [3]. Early research in the field primarily relied on subjective measures of the built environment but now health researchers are embracing Geographic Information Systems (GIS) as a tool to objectively measure the built environment and its influence on human health. GIS allows for quantification of spatial phenomena such as population density, road network configuration, and access to facilities [1]. Meanwhile, measures of physical activity, which initially relied on self-report methodologies, are moving towards more objective monitoring, for example using accelerometers [4]. Despite advances in objectively measuring both the built environment and physical activity, one area that remains lacking is an objective measurement of how people actually behave and utilize the built environment for physical activity. In other words, a more precise approach that spatially contextualizes physical activity behaviors is needed [5, 6]. Technology in the form of global positioning systems (GPS) can bring a solution to this issue. Using GPS allows for an objective measure of an individual's movement through the built environment, and when coupled with accelerometry, can provide a good spatial representation of where physical activity actually occurs. Subsequently, data of this type can best be appreciated and understood when integrated into GIS.

To this aim, the following paper first overviews the current 'state of science' for GPS use in health research examining built environment influences on health. Then, a case study of how GPS tracking data has been used in a recent study of older adults in the Perth Metropolitan region will be presented. Results from the 'state of science' discussion and older adult research in Perth identify the utility of GPS tracking data in expanding our understanding of human environment interactions in the field of population health.

2. STATE OF SCIENCE

Portable GPS units are a relatively inexpensive, non-invasive, and non-obtrusive method for objectively capturing the time, date, location, and speed at which individual's move through their environment [5, 7, 8]. Furthermore, GPS units with adequate memory allow continuous data to be collected over long periods of time [9, 10]. Coupling data from GPS units with accelerometers, which involves linking the time stamps from both, provides an objective, accurate method for assessing location-based physical activity [11, 12]. The advantage of this technology is that the data can be visualized and applied to every individual independent of walking style and terrain [9]. In addition to examining physical activity levels at specific locations, physical activity levels (from accelerometer data) and speed of movement (from GPS data) can be used together to more accurately classify physical activities by type (i.e., running, walking, cycling etc.) [12]. This then provides the capacity to spatially link built environment measures to specific types of physical activities [5]. This section outlines the current evidence on GPS device selection, findings from the health literature, and methodological considerations.

2.1. GPS Device Selection

Currently, personal GPS data collection devices range from small appliances that can be worn on a belt or around the waist, to mobile phone based technologies. Early units were quite cumbersome; however advances in technology have resulted in units, which can be worn on the wrist in free living conditions, with the ability to collect corrected signals such as the Wide Area Augmentation System (WAAS), thus increasing positional accuracy [13]. GPS data collection in health research currently relies on a few cost-effective devices, such as the Garmin Foretrex [14, 15] and the Geologger by GeoStats [16], but attention is also being given to the use of mobile phones with GPS data logging capabilities as an even less intrusive approach.

2.2. Use of GPS Technology in Physical Activity Research

While early studies in the field were primarily concerned with the feasibility of using personal GPS data logs for health-related inquiry [5, 17], researchers are now beginning to link GPS data with other objective data to better measure the built environment and physical activity. For example, Badland et al [18], compared shortest commute routes (derived from GIS) with actual commute routes (derived from GPS), and then compared exposure to different features of the built environment along participant's routes to work, according to mode of transport (i.e., public transport, walking for transport, and personal vehicle). Similar research comparing GIS and GPS routes has been conducted in children [17]. Troped and colleagues [6] used GPS, accelerometry, and GIS to examine the relationship between moderate- to vigorous-intensity physical activity (MVPA) and several built environment measures within 50m and 1km buffers of participant's residence and workplace. Though the previous studies focused on adults, GPS technology has been employed more in tracking the movement and physical activity levels of children and adolescents.. Using GPS derived data, studies have examined the time and distribution of MVPA [19], as well as the seasonal patterns of physical activity [14]. Moreover, several studies have gone further, examining the relationship between location and physical activity type and vigor [12, 15, 20, 21]. In summary, findings from both child and adult populations have important implications for the progression of research in the built environment and physical activity field. What is evident from advances in both technology and research is that GPS, when used in collaboration with GIS and accelerometry, offers a rigorous opportunity to explore objectively measured physical activity that is spatially linked to specific location contexts, and its relationship with exposure to built environment features.

2.3 Methodological Considerations

At this point it is important to note that the use of GPS technology in physical activity research is not without its complications and issues that warrant further attention. For example, satellite interference from urban canyons or tree cover can produce signal loss or signal scatter that can make the identification of tracks from GPS points difficult. In addition, tracks can sometimes include speeds and distances that are not theoretically plausible. For studies interested in the influence of the built environment on physically active travel behaviors, making sense of GPS point data requires categorization of tracks by transport mode (e.g., walking for transport, bicycling, motor vehicle, public transport etc.). Complexity levels of categorization methods vary, but generally rely on information collected by the GPS receiver itself, including start and end time of movement, and average speed [12, 22]. Ancillary data, for example transportation network attributes, can also provide additional information allowing physical activity classification based on network link rules such as speed and direction of travel [23]. The combination of GPS data with accelerometer data can also assist in classifying trips, as the change in movement intensity measured by the accelerometer can help to distinguish travel modes, particularly those with similar speeds.

Linking GPS data with accelerometers can be labor intensive and complicated. Recently, the University of California, San Diego has developed an online system – the Physical Activity and Location Measurement System (PALMS) – for linking wearable sensor data with GPS data logs for use within a GIS. This is done by matching the time stamps of data from each unit type. PALMS provides users with the ability to classify trips (or bouts) based on type of activity. The interactive interface allows for the adjustment of a variety of parameters (e.g., speed and sedentary times) and incorporation of ancillary information (e.g., acceleration and heart rate) to classify bouts based on specific sample characteristics [24].

3. AN APPLICATION IN PERTH, WA

The previous section outlined the current state of science for the use of GPS technology in physical activity research, but there are other ways in which this technology can also enhance the understanding of built environment influences on physical activity. This section overviews how GPS technology has been utilized to explore definitions of 'neighborhood'.

3.1. Definitions of 'Neighborhood'

Much of the scholarly literature examining the relationship between the built environment and physical activity uses the standard approach of 'neighborhood' – the radial or network based area surrounding an individual's residence – as a spatial delineator for deriving built environment measures. However, this seemingly arbitrary definition makes the assumption that the immediate area surrounding a person's home is the area used for activity. The development and refinement of GPS technology allows for a revisit of some of these fundamental geographic assumptions as we can now examine what areas near to home do participants actually travel and utilize. Thus, to further examine the link between 'neighborhood' definition, built environment measures, and physical activity, this initial case study created a series of buffering techniques for spatially defining 'neighhborhood' based on objective GPS data tracking actual movement through environments.

3.1. Methods

Research participants were a subset of older adults from a larger investigation focusing on residents of retirement village housing and relationships between village environment, neighborhood environment, and active living. Of the original 325 older adults (from 32 retirement villages), a sample of 41 (living in seven different villages) agreed to wear a GPS unit and accelerometer for seven days in November and December of 2009. Participants wore the devices - a GlobalSat DG-100 GPS data logger (recording position every 15 seconds) and GT1M ActiGraph accelerometer (recording in one minute epochs) – on a belt placed either above or under their clothing, and were provided with instructions for use.

The data were processed using the PALMS platform to aggregate GPS points into trips that were then categorized based on activity type. All classified trips were visually assessed by first overlaying the GPS points on high resolution aerial photography. Average speed was then visually compared with terrain and examined for increases or decreases in speed and erroneous stationary points. This often resulted in manually splitting a trip into two or more trips [13].

To compare land-use exposure of GPS derived walking trips with land-use exposure estimates measured using 'neighborhood' buffers, the average percentage of each land-use (commercial; institutional; recreational and park; industrial; residential; utilities/communications; other) was first calculated for all walking trips (based on a 50m buffer along each route calculated using Hawth's

Animal Movement Tools) (Figure 1a) [21]. Then a series of commonly used buffers were calculated for each participant using the central location of their retirement village. These included standard radial buffers, network buffers, and line-based network buffers [21], all based on a distance of 1000m, the furthest distance any participant traveled from their home (Figure 1b). For each buffer, the average percent of each land-use for each participant was then calculated.

Using the personal GPS data locations for walking trips, several additional buffering techniques were explored, informed by the contextual information provided by knowing exactly where participants walked (Figure 1b and c). First, variable width buffers were calculated based on exposure to specific land-use types (Figure 1b). Using participant GPS data, weights (based on exposure) were developed for each land-use category reflecting the ease of moving across each and were calculated as 1 minus the average percent exposure to each land cover for all participants (*residential*= 57; *other*=.64; *recreational and park*=.93; *institutional*=.98; *industrial*=.99; *utilities/communications*=.99). Variable width buffers were then calculated as a 'cost distance' representing the cost to move across each land-use type. The variable width buffer was then constrained by the total cost to move 1km from the point of origin if only exposed to *residential* lands (the easiest land-use to move across).

Through the visual examination of actual walking data, participants appeared to walk mostly to *recreational and park*, *institutional*, and *commercial* (RIC) facilities (also identified within the literature [23, 25]). Three additional buffer techniques were then explored to incorporate RIC facilities including: RIC line buffers, developed by buffering the shortest routes along the road network from each participants home to each of the RIC facilities; RIC polygon buffers, created with the Hawth's Convex Hull tool where the smallest convex was set to include all RIC points within 1km of the participant's home; and RIC ellipse buffers, where the standard deviation of distance between RIC facilities was used to create an ellipse indicating directional trend in facility locations (Figure 1c). The mean percent land-use exposure for each land-use category for each buffer type was then compared with mean percentage land-use exposure along actual walking trips, as identified above.

Figure 1: Examples of GPS tracks (a.), commonly used buffers (b.), and new buffers (c.)

3.2. Results

Initially, PALMS detected 1632 trips in the total GPS dataset and after treatment, 82 trips (5%), distributed over 20 participants, were classified as walking trips. Participants were divided equally between male and female with an average age of 73 years (Table 1). Participants averaged 4.1

walking trips over the seven day period, with an average duration of 26 minutes, distance of 1.76km, and speed of 4.08km/h (table 2).

Variable (N=20)	
Gender	50% male, 50% female
Age	M=73.30, SE=1.70
Height (m)	M=1.68, SE=.03
Weight (kg)	M=74.3, SE=3.33

Table 1: Participant characteristics – demographic information

Variable (N=82)	Average
Trips per participant	4.1
Trip-days per participant	2.95
Duration of trip	26.2 min
Distance of trip	1.76 km
Speed of trip	4.08 km/h

Table 2: Characteristics of identified walking trips

Based on GPS walking tracks, participants were exposed most to *residential*, *commercial*, and *recreational and park* land and least to *utilities/communications* and *industrial* lands (excluding *other*) (Table 3). In comparison with circular, network and line based network buffers, each underestimated exposure to *commercial* and *industrial* lands and overestimated exposure to *institutional* and *utilities/communications* lands. Varying exposure results were produced for *recreational and park* lands and *residential* lands: circular buffers overestimated exposure; and network and line-based network buffers underestimated exposure. The opposite was true for *residential* lands, where circular buffers underestimated exposure, while network and line-based buffers overestimated exposure.

Land use type	GPS Walking tracks		Circular		Network		Line-based network	
	M	SD	M	SD	M	SD	M	SD
Commercial	11.65	14.07	5.17	3.48	9.48	8.42	8.05	7.20
Institutional	1.86	5.66	3.71	3.36	2.83	2.30	2.25	1.30
Recreational and park	6.71	11.98	10.67	12.21	5.79	4.07	4.47	2.72
Industrial	0.82	2.28	0.23	0.40	0.14	0.23	0.13	0.22
Residential	42.63	17.49	35.35	6.35	45.45	10.04	46.16	11.46
Utilities / Communications	0.74	1.52	0.55	0.35	0.41	0.46	0.40	0.47
Other	35.59	12.89	44.31	24.92	35.90	5.88	38.53	6.43

Table 3: Difference in percent land-use exposure based on GPS derived walking trips and commonly used circular, network and line-based network buffers at 1000m

In comparing GPS walking tracks with variable width, RIC polygon, RIC ellipse, and RIC line-based buffers, exposure to *institutional* and *recreational and park* lands were overestimated while exposure to *industrial* and *residential* lands were underestimated. Exposure varied with *commercial* and *utilities/communications* lands, where variable width buffers underestimated exposure to *commercial* lands, and overestimated exposure with RIC polygon, RIC ellipse and RIC line-based buffers. Conversely, exposure to *utilities/communications* lands were underestimated with variable width, RIC polygon, and RIC line-based buffers but overestimated with RIC ellipse buffers.

Land use type	GPS Walking tracks		Variable Width		RIC polygon		RIC ellipse		RIC line	
	M	SD	M	SD	M	SD	M	SD	M	SD
Commercial	11.65	14.07	5.68	3.67	14.69	7.51	39.00	17.43	22.93	13.29
Institutional	1.86	5.66	3.61	3.36	4.43	3.05	2.83	3.92	2.92	3.96
Recreational and park	6.71	11.98	10.36	12.54	12.67	17.05	11.34	10.83	8.37	4.73
Industrial	0.82	2.28	0.15	0.21	0.63	1.10	0.19	0.39	0.31	0.48
Residential	42.63	17.49	36.51	17.14	34.95	11.43	14.55	13.48	25.11	9.96
Utilities/ Communications	0.74	1.52	0.51	0.31	0.58	0.47	0.90	1.08	0.52	0.54
Other	35.59	12.89	43.19	25.11	32.04	11.14	31.19	13.64	39.84	7.94

Table 4: Difference in percent land-use exposure based on GPS derived walking trips and new variable width, RIC polygon, RIC ellipse and RIC line buffers at 1000m

4. DISCUSSION AND CONCLUSION

An initial examination of the case study results indicate that variation in land-use exposure exists between estimates calculated using the GPS walking tracks and those derived using each buffer technique. Variation appears to be greatest with some of the new buffering techniques; however it is apparent that no single buffer technique provides the best estimate of land-use exposure when compared with GPS walking tracks. Though results presented here provide an initial investigation, further analysis is required to examine the ability of land-use exposure measures calculated using each type of buffer to predict propensity for engagement in physical activity.

Through an initial overview of the ‘state of science’ in the use of GPS technology in health research, this paper highlights the possibilities for improving the ways in which we examine the interaction between physical activity and the environment in which it occurs. Furthermore, GPS technology provides the ability to re-examine our traditional approaches to measuring the built environment. This in turn may produce better understandings of the most important features within a neighborhood for promoting physical activity. Through the examination of how we engage with our environment and the features we regularly engage with, planners and policy makers are provided with the scientific foundation needed to design neighborhoods conducive to healthy lifestyles.

REFERENCES

[1] Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF: Measuring the built environment for physical activity state of the science**.** *American journal of preventive Medicine*, Vol. 36, No. 4, pp. 99–123 (2009).

[2] Humphrey NP: Does the built environment influence physical activity? *Transportation Research Board Special Report, TR News,* Vol. 237, pp. 31-33 (2005).

[3] Transportation Research Board and Institute of Medicine of the National Academies: *Does the built environment influence physical activity? Examining the evidence*, Washington, DC: Transportation Research Board, Institute of Medicine of the National Academies (2005).

[4] Ward DS, Evenson KR, Vaughn A, Rodgers AB, Troiano RP: Accelerometer use in physical activity: best practices and research recommendations. *Medicine & Science in Sports & Exercise,* Vol. 37, pp.S582-S588 (2005).

[5] Rodríguez DA, Brown AL, Troped PJ: Portable global positioning units to complement accelerometry-based physical activity monitors. *Medicine & Science in Sports & Exercise,* Vol. 37, 11S, S572-S581 (2005).

[6] Troped PJ, Wilson JS, Matthews CE, Cromley EK, Melly SJ: The built environment and location-based physical activity. *American Journal of Preventive Medicine,* Vol. 38, No. 4, pp. 429-438 (2010).

[7] Schutz Y, Herren R: Assessment of speed of human locomotion using a differential satellite global positioning system. *Medicine & Science in Sports & Exercise,* Vol. 32, No. 3, pp. 642-646 (2000).

[8] Townshend AD, Worringham CJ, Stewart IB: Assessment of speed and position during human locomotion using nondifferential GPS. *Medicine & Science in Sports & Exercise,* Vol. 40, No. 10, pp. 124-132 (2007).

[9] Schutz Y, Chambaz A: Could a satellite-based navigation system (GPS) be used to assess the physical activity of individuals on earth? *European Journal of Clinical Nutrition,* Vol. 51, pp. 338-339 (1997).

[10] Maddison R, Mhurchi CN: Global positioning system: A new opportunity in physical activity measurement. *International Journal of Behavioral Nutrition and Physical Activity, Vol.* 6, pp. 73-80 (2009).

[11] Oliver M, Badland H, Mavoa S, Duncan MJ, Duncan S: Combining GPS, GIS, and accelerometry: Methodological issues in the assessment of location and intensity of travel behaviors. *Journal of Physical Activity and Health,* Vol. 7, pp. 102-108 (2010).

[12] Quigg R, Gray A, Reeder AI, Holt A, Waters DL: Using accelerometers and GPS units to identify the proportion of daily physical activity located in parks with playgrounds in New Zealand children. *Preventive Medicine*, Vol. 50, pp. 235-240 (2010).

[13] Cho GH, Rodríguez DA, Evenson KR: Identifying walking trips using GPS data. *Medicine & Science in Sports & Exercise,* (2010-published ahead of print).

[14] Cooper AR, Page AS, Wheeler BW, Hillsdon M, Griew P, Jago R: Patterns of GPS measured time outdoors after school and objective physical activity in English children, the PEACH project. *International Journal of Behavioral Nutrition and Physical Activity*, Vol. 7, pp. 31 (2010).

[15] Wheeler BW, Cooper AR, Page AS, Jago R: Greenspace and children's physical activity: A GPS/GIS analysis of the PEACH project. *Preventive Medicine,* Vol. 51, pp. 148-152 (2010).

[16] Stopher P, FitzGerald C, Zhang J: In Search of a GPS Device for Measuring Personal Travel. *Special Issue of Transportation Research C, on Emerging Commercial Technologies,* Vol. 16, pp. 350-369 (2008).

[17] Duncan MJ, Mummery WK: GIS or GPS? A comparison of two methods for assessing route taken during active transport. *American Journal of Preventive Medicine,* Vol. 33, No. 1, pp. 51-53 (2007).

[18] Badland HM, Duncan MJ, Oliver M, Duncan JS, Mavoa S: Examining commute routes: applications of GIS and GPS technology. *Environmental Health and Preventative Medicine,* Vol. 15, pp. 327-330 (2010).

[19] Maddison R. Jiang Y, Hoorn SV, Exeter D, Mhurchu CN, Doery E: Describing patterns of physical activity in adolescents using global position systems and accelerometry. *Pediatric Exercise Science*, Vol. 22, pp. 392-407 (2010).

[20] Jones AP, Coombes EG, Griffin SJ, Van Sluijs EMF: Environmental supportiveness for physical activity in English schoolchildren: a study using Global Positioning Systems. *International journal of Behavioral Nutrition and Physical Activity,* Vol. 6, pp. 42-49 (2009).

[21] Maddison R. Jiang Y, Hoorn SV, Exeter D, Mhurchu CN, Doery E: Describing patterns of physical activity in adolescents using global position systems and accelerometry. *Pediatric Exercise Science*, Vol. 22, pp. 392-407 (2010).

[22] Copeland JL, Esliger DW: Accelerometer assessment of physical activity in active, healthy older adults. *Journal of Aging and Physical Activity,* Vol. 17, pp. 17-30 (2009).

[23] Chung E, Shalaby A: A trip reconstruction tool for GPS-based personal travel surveys. *Transportation Planning and Technology*, Vol. 28, No. 5, pp. 381-401 (2005).

[24] Center for Wireless and population Health Systems: UCSD Palms Project. Retrieved May 23, 2011 on: https://ucsd-palms-project.wikispaces.com/.

[25] Cervero R, Duncan M. Walking, bicycling, and urban landscapes: evidence from the San Francisco Bay Area. *Am J Public Health*, Vol. 93, pp. 1478–83 (2003).

[28] Oliver LN, Schuurman N, Hall AW: Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *International Journal of Health Geographics*, Vol. 6, pp. 41-51 (2007).

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

On the Virtual Moon Framework and the Virtualization Technology of Chang'e-1 Lunar Satellite Data

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ABSTRACT

In the 21st century, countries throughout the world have given much attention to lunar exploration, which is also the independent innovation highlight in aerospace science and technology in China. The launch of Chang'e-1 Lunar Satellite and the construction of the scientific observational data platform have provided opportunities for China's research on lunar geometry, physical and chemical environment. First of all, this paper proposes the concept of Virtual Moon, under which the system structure and framework are deduced. Then, taking the latest optical images captured by Chang'e-1 Lunar Satellite as an example, 3D presentation of mass quantities of lunar data is achieved within the Virtual Moon framework, based on the open source tool WorldWind developed by NASA. This paper elaborates on the crucial technologies, including image data pre-processing, image projection transformation, image mosaic and image pyramid. Finally, the significance of Virtual Moon in future lunar exploration programs is analysed. ***Keywords:*** Virtual Moon; Chang'e-1 Lunar Satellite; Image Pyramid; WorldWind

1. INTRODUCTION

With the development of modern aerospace technology and deep space exploration, man's exploration into the moon has become a great interest in the field of aerospace since last century (Compton 1989, Ouyang 2005, Marais et al. 2008, Kirk et al. 2009). It has been decades since the developed countries first started the exploration and research of the moon. After the Apollo Program, the US has initiated and launched several key Lunar Exploration Projects, with accelerating pace in lunar exploration (Seamans 2005). Following the US, Russia and Japan made national plan for lunar exploration, preparing for their exploitation of lunar resources (Galimov et al. 1999, Sasaki et al. 2002, Takano et al. 2005, Harvey 2007). China, among the countries possessing advanced aerospace and aeronautical technologies, has made substantial achievements in space scientific research and exploration activities. The successful launch and operation of Chang'e-1 marks China's breakthrough in this field. Lunar exploration has significant influence in the following aspects: it deepens human-beings' knowledge of outer space creatures and the scale of space and time; meanwhile, it contributes to the conduction of space researches and experiments through the utilization of unique physical and chemical properties of lunar atmosphere, which is impossible on earth; moreover, it may provide resources for mankind's sustainable development, as preliminary study showed that the moon has abundant rare metal and mineral resources, as well as high-efficience clean energy such as helium-3. Therefore, to survive the increasingly heated resource extraction and reservation competition between the nations, and to satisfy the strategic needs of China's long-term resource development, planning and sustainable development, it is necessary for China to treat lunar exploration programs and future lunar resource exploitation plan as important space strategies in the planning of national high technology development.

The capture and delivery of the geometric information of lunar space have always been the primary task to lunar exploration programs. The successful operation Chang'e-1 lunar satellite has established the scientific platform for obtaining lunar observational data, providing mass quantities of observational information of lunar geometry, including optical images and laser altimetry data (Zheng et al., 2008). Therefore, it is highly necessary to select suitable theoretical framework, and to develop special technology to organize and represent these data. The data obtained by Chang'e-1 Lunar Satellite are typical remote sensing data characterized by multi-sensor, multi-scale and large capacity, with higher requirement on the organization, management and presentation techniques of lunar observational data. At present, the virtualization approaches are mainly based on categorical document management and a two-dimensional lunar image presentation based on image mosaic, which lacks a well-organized three dimensional interactive lunar presentation system with the characteristics of large scale, full coverage and multiple attributes for Chang'e-1 data visualization.

In order to achieve a more effective virtualization analysis of lunar data captured by Chang'e-1 Lunar Satellite, by adopting the idea of Virtual Geographical Environment, this paper proposes the concept of virtual moon and establishes its technical frame that offers a better 3D visualization environment for analysis of earth-moon interaction of lunar data. Meanwhile, taking the latest optical images captured by Chang'e-1 Lunar Satellite as example, the 3D virtual lunar framework is realized with open source tool WorldWind as the platform. This paper makes a detailed elaboration on the crucial technology in the realization chain of Virtual Moon Framework, including image data pre-processing, image projection transformation, image mosaic and image pyramid. Finally, the significance of Virtual Moon in future lunar exploration programs is analyzed.

2. THE CONCEPT AND SYSTEM STRUCTURE OF VIRTUAL MOON BASED ON THE IDEA OF VIRTUAL GEOGRAPHICAL ENVIRONMENT

2.1. Virtual Geographical Environment and its architecture

21st century witnesses the rapid development of computer science, database and internet, and human beings' language to express the earth's environment and geographical information have evolved from scripts, maps, geographical information systems to higher stages, and the concept of Virtual Geographical Environment (VGEs) was raised at the end of last century. VGEs is defined as the subject, the embodiment of human society, and the all the objective environment surrounding the subject, including software and hardware settings of computers and the internet, data environment, virtual image mirroring environment, virtual economic environment, as well as social, political and cultural environment（Lin & Gong 2002, Lin and Zhu 2006, Lin and Batty 2008, Lin and Chen 2011）. The embodiment of human society refers to the ensemble of human beings in the real world and their embodiments in the virtual world. According to the scale, the real world is categorized into planets such as earth and moon, natural circles and biological reproduction domain, cities where people dwell in a compact community, artificial architecture and natural landscapes. The conceptual framework of VGEs is illustrated in Figure 1.

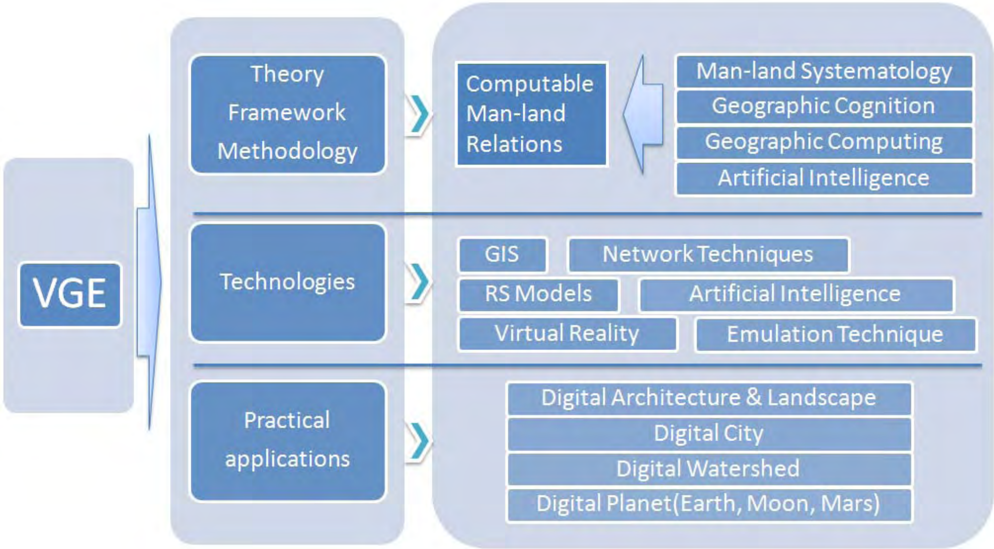

Figure 1: The conceptual framework of VGEs(Lin&Gong, 2002)

2.2. The concept of Virtual Moon based on VGEs

The US former vice president Al Gore proposed the concept of Digital Earth in the year 1998. Digital Earth is a technological system which is characterized by multiple resolutions, mass quantities of data, 3D presentation of the earth, and is based on geographical coordinates (graticule) (Goodchild 2000). Digital Earth refers to Digitalized Virtual Earth, with its connotation of Virtual Geographical Environment, and is one of the practical forms and layers of Virtual Geographical Environment.

Under the framework of Virtual Geographical Environment, the idea of Virtual Moon is the extension of Virtual Geographical Environment via the expression of lunar information. Virtual Moon is a technical system, with observational data characterized by multiple resolutions and multi-sensors, and 3D presentation of the moon, based on lunar geographical coordinates (graticule). Virtual Moon is a new extension of Virtual Geographical Environment.

2.3. Virtual Moon Framework

Based on the idea above, Virtual Moon Framework is illustrated in Figure 2. In this framework, not only strategies for information sharing and 3D visualization are considered, but process models are added to help further analysis.

3. REALIZATION OF VIRTUAL LUNAR TECHNOLOGY

Based on the data captured by Chang'e-1 Lunar Satellite, virtual lunar realization technologies included two parts, namely, data pre-processing and visualization system construction in this study.

(1) Data preprocessing: including geometric calibration, mosaic, dodging, image enhancement and image pyramid generation.

(2) Visualization system construction: through the application of the open resource platform WorldWind, a 3D presentation platform is established based on data captured by Chang'e-1 Lunar Satellite, which is responsible for mapping users' data onto the sphere and providing a real-time virtual-moon roaming. In addition, raw data storage, processing program and 3D presentation platform are designed separately to enhance the flexibility of platform in this study. In this way, the process of management and overlaying can be carried out on lunar data without modifying the 3D platform.

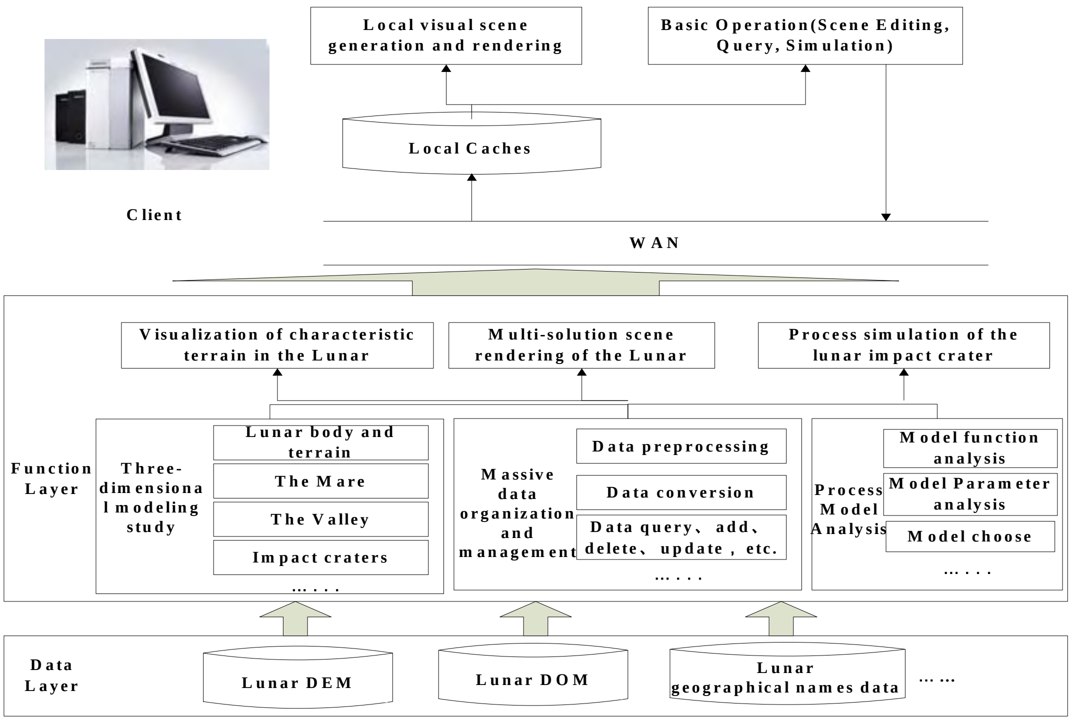

Figure 2: The framework of Virtual Moon

3.1. Pre-processing of Chang'e-1 Lunar Satellite Data

3.1.1 Chang'e-1 Lunar Satellite detection data and CCD images

As China's first lunar probe developed and launched independently, Chang'e-1 lunar satellite is a scientific exploration platform equipped with 8 detection instruments, such as CCD stereo camera, laser altimeter and interference imaging spectrometer(http://159.226.88.59:7779/CE1OutWeb/). Its main task is to obtain 3D images of lunar surface, analyzes the distribution of elements on lunar surface, and detects the thickness of lunar soil as well as cislunar space environment. The observational data acquired by Chang'e-1 probe can provide basic scientific data for lunar geometric and physical analysis.

The CCD stereo camera carried by Chang'e-1 lunar satellite can be used to obtain three optical images of lunar surface target, namely, sub-stellar point (intermediate sight), foresight and back-sight images. CCD images have high resolution with horizontal length of 120 m and width of 60 km, covering the lunar surface between north latitude of 75^0 to south latitude of 75^0.

Lunar CCD images are published by classification in accordance with PDS (Planetary Data Standard) format. Those released to scientific users are level-3 PDS image data products after radiometric, geometric and photometric calibration as well as deep processing. Each set of products include lunar surface optical images and the corresponding geometric calibration information.

The geometric calibration information of level-3 PDS image products based on Chang'e-1 lunar satellite data provides the pixel coordinates of images as well as the latitude and longitude in lunar reference system. These latitude and longitude constitute the space geodetic coordinates with the centre of lunar sphere as the coordinate origin based on lunar reference ellipsoid. The parameters of lunar reference ellipsoid are shown in Table 1.

Lunar parameter	Value
Average radius of the moon	1,737,013m
Average equatorial radius	1,737,646m
Polar radius	1,735,843m
Lunar oblateness	1/963.7256

Table 1 Parameters of lunar ellipsoid

Based on the lunar ellipsoid parameters in Table 1, the lunar geodetic coordinates were projected to the lunar plane coordinates by 35° conformal cylindrical projection method along the vertical axis of Mocato(Su & Pu, 2008). Mercator projection, also known as normal cylindrical conformal projection, was created by Dutch cartographer G. Mercator in 1569. As no changes occur to original direction and angle in the map after Mercator projection, this method is preferred for lunar projection and mapping.

Mercator plane rectangular coordinate system was constituted by the origin as the projection of intersection point between lunar prime meridian (longitude 0°) and the equator, the vertical axis (i.e., X axis) as the projection of prime meridian, and the abscissa (i.e., Y axis) as the projection of the equator. By positive solution transformation, geodetic coordinates were projected onto plane coordinates. The projection model is shown as follows:

$$X_N = K \ln[tg(\frac{\pi}{4}+\frac{B}{2}) * (\frac{1-e\sin B}{1+e\sin B})^{\frac{e}{2}}]$$

$$Y_E = K(L - L0)$$

$$K = N_{B0} * \cos(B0) = \frac{a^2 / b}{\sqrt{1+e'^2 * \cos^2(B0)}} * \cos(B0)$$

Where e is the napierian base; a and b are the equatorial and polar radius of the moon, respectively; e' is the first eccentricity of the moon; the latitude B0 is taken as the normal latitude.

3.1.2 3D coordinates of CCD images

The lunar level-3 CCD images provided geodetic coordinates in lunar reference system for 3D mosaic and visualization expression. The lunar geometric calibration document needed to be converted from PDS format to geotiff format supported by ENVI. Meanwhile, artificial geometric displacement was carried out in the imaging area with the coverage from positive longitude of 180° to negative longitude of180°, so that the continuity was maintained in the post re-sampling and mosaic.

3.2. Construction of lunar 3D visualization system

3.2.1 Strip mosaic technology

As the published lunar images are strip-shaped (with a longitude width of 6-10 ° and a latitude ranging from 75 ° N to 75 ° S), mosaic was thus required for image strips, in order to reduce the mosaic errors between images. Every 20 original sub-images were made into a mosaicked image in this study. In addition, according to the requirement of image plane accuracy after re-sampling (higher than 130 m), it was necessary to determine the spacing of control points in the images for uniform selection of control points. Based on the coordinates of control points in lunar coordinate reference system, the geometric model parameters were solved, and re-sampling was carried out to eliminate the inconsistencies between images. By this means, the geometric correction on image data was completed and multi-image mosaic was realized.

The CCD camera breadth of Chang'e-1 lunar satellite is 60 km, and each orbit has a number of repetitive areas, which is fewer in areas adjacent to the equator. To improve the consistency of image color, reduce the number of image pyramid layers and to improve efficiency, it was necessary to take 10 strips as a set in this study. Mosaic and dodging were conducted on the data after geometric correction.

3.3.2 Image pyramid technology

For data organization of images and DEM, because the multi-resolution pyramid approach can not only regulates the data volume by providing suitable resolution data when downloading and transmitting, but also avoids unnecessary data access (Camara et al. 2008); this approach was employed to compress and partition the entire image and DEM. By this method, data with different resolutions can be generated based on original images, and the amount of downloaded and transmitted data can be controlled; meanwhile, unnecessary data access is avoided to support the high-efficiency presentation of massive image data. In this study, the common tile pyramid technology was used for data compression and block processing on the whole image and the whole DEM data. The pyramid is model with multiple hierarchies of resolution. In mapping the topographic scene on the premise of ensuring the presentation precision, digital elevation model data and texture image data with different resolutions are often required for different regions, in order to improve the presentation speed. Digital elevation model pyramid and image pyramid can directly provide satisfactory data without real-time re-sampling. The pyramid image system is also used in WorldWind to realize image scheduling and presentation mechanism (Bell et al, 2007).The realization strategy of Worldwind image pyramid is shown in Figure 3.

By referring to WorldWind segmentation method on images and DEM data, the images and DEM data were processed by hierarchical segmentation to generate pyramid tile data which could be directly scheduled by WorldWind.

3.3.3 Visualization of Virtual Moon

WorldWind supports data configuration by XML document. Therefore, necessary configuration was conducted on the processed data in accordance with response parameters for 3D presentation via WorldWind client. The presentation results are shown in the figure 4:

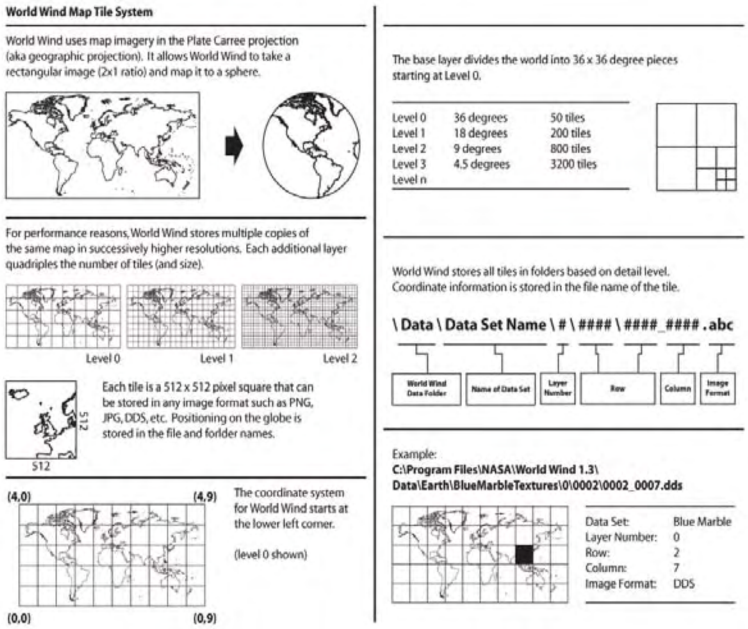

Figure 3: Image pyramid strategy of Worldwind
(Bigheader, http://wenku.baidu.com/view/87e8a8791711cc7931b716fb.html)

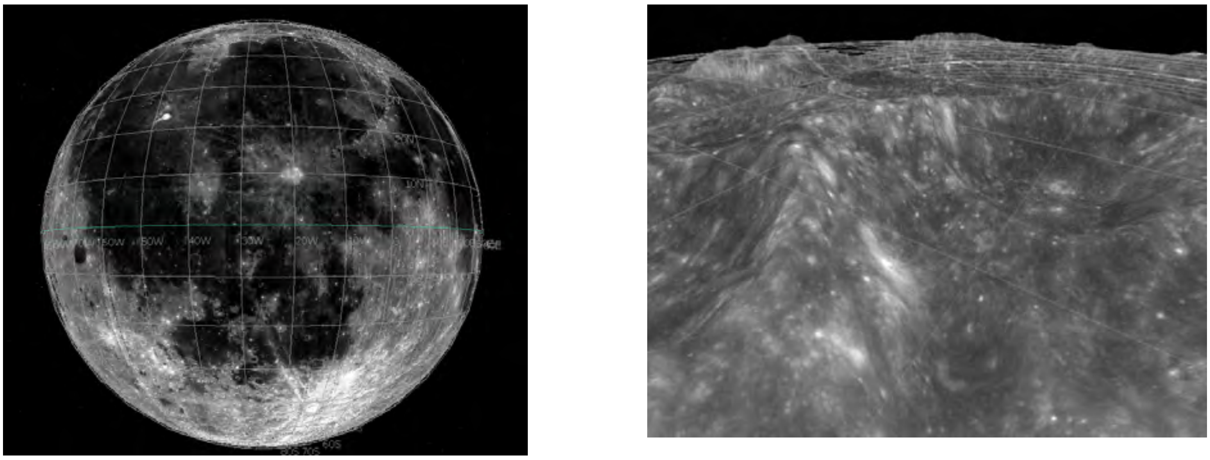

Figure 4: Virtualization of virtual Moon

4. CONCLUSION

The virtual reality technology, characteristics of virtual moon and problems are firstly discussed in this study. Then, the application of virtual moon in lunar research is investigated. The computer framework, data service and sharing mechanism of virtual moon are designed. Finally, a simple prototype system was established based on Chang'e-1 lunar satellite data and WorldWind. Additionally, preliminary verification tests were carried out. The results proved the feasibility of the scheme proposed in this study, which provided virtual reality-based research ideas and methods for lunar research. Virtual Moon is taken as a new research orientation with many aspects remaining to be studied. The 2D data accuracy of lunar surface has reached an advanced level, but the resolution and coverage of 3D topographic data are still very low. Therefore, the subsequent task of this study is to use stereo camera data of Chang'e-1 lunar satellite to retrieve 3D topography of lunar surface, so as to facilitate the research and understanding of the moon and to enrich the information of virtual moon. In this way, the application value and significance of virtual moon platform can be deepened.

Acknowledgements

The work described in this paper was supported by the Key Program of National Natural Science Foundation of China (grant no.40730527), the National High Technology Research and Development Program of China (key "863" no. 2010AA122202), the National Natural Science Foundation of China (grant no. 41001223). We also appreciate the detailed suggestions and comments from the editor and the anonymous reviewers.

References:

[1]. Bell, D. G., Kuehnel, F., Maxwell, C., Kim, R., Kasraie, K., Gaskins, T., Hogan, P., and Coughlan, J. 2007. NASA World Wind: Opensource GIS for Mission Operations. Aerospace Conference IEEE. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4161692. [Accessed May 8th 2011].

[2]. Camara, G., Vinhas, L., Ferreira, K. R., Queiroz, G. R. D., Souza, R. C. M. D., Monteiro, A. M. V., Carvalho, M. T. D., Casanova, M. A., and Freitas, U. M. D. 2008. TerraLib: An Open Source GIS Library for Large-Scale Environmental and Socio-Economic Applications. Advances in Geographic Information Science, 2: 247-270.

[3]. Compton, W. D. 1989. Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions. http://www.spacearium.com/filemgmt_data/files/SP-4214.pdf. [Accessed May 6th 2011].

[4]. Galimov, E. M., Kulikov, S. D., Kremnev, R. S., Surkov, Y. A., and Khavroshkin, O. B. 1999. The Russian Lunar Exploration Project. Solar system Research, 33: 327.

[5]. Harvey, B. 2007. Soviet and Russian lunar exploration. Praxis Publishing Ltd, UK.

[6]. Kirk, R. L., Archinal, B. A., Gaddis, L.R., and Rosiek. 2009 Cartography for lunar exploration: 2008 status and mission plans. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII(B4): 1473-1490.

[7]. Lin, H. and Gong, J. H. 2002. On Virtual Geographic Environments. In Selected Papers for English Edition- Acta Geodaetica et Cartographic Sinica, ed. Editorial Dept. of Acta Grod.Cartog.Sin, 90-95. Beijing: the Publishing House of Surveying and Mapping.

[8]. Lin, H. and Batty, M. 2008. *Virtual Geographic Environments: A Primer*. ed. H. Lin, and M. Batty, 1–10. Beijing: Science Press.

[9]. Lin, H., and Chen, M. 2011. Virtual Geographic Environments- an evolution from map and Geographic Information System. *The Annals of the Association of American Geographers*. Submitted.

[10]. Lin, H. and Zhu, Q. 2006. Virtual Geographic Environments. *In Large-scale 3D Data Integration: Challenges and Opportunities*, ed. S. Zlatanova, and D. Prosperi, 211–230. Boca Raton: Taylor & Francis.

[11]. Marais, D. J. D., Nuth III, J. A., Allamandola, L. J., Boss, A. P., Farmer, J. D., Hoehler, T. M., Jakosky, B. M., Meadows, V. S., Pohorille, A., Runnnegar, B., and Spormann, A. M. 2008. The NASA Astrobiology Roadmap. Astrobiology, 8(4): 715-730.

[12]. Ouyang, Z. Y. 2005. Introduction to lunar science. Beijing, China Aerospace Press.

[13]. Sasaki, S., Kubota, T., Okada, T., Saiki, K., Kuroda, Y., Kunii, Y., Shibamura, E., Akiyama, N., Ohtake, M., Ichikawa, M., Higa, M., Hirata, N., Sugihara, T., Haruyama, J., Otake, H., Yoshioka, N., Terazono, J., Yamada, M., Yamaguchi, Y., Kodam, S., and Rover Group in Japan. 2002. Scientific exploration of lunar surface using a rover in Japanese future lunar mission. Advances in Space Research, 30(8): 1921-1926.

[14]. Seamans, R. C. 2005. Project Apollo: the tough decisions. National Aeronautics and Space Administration. History Office, USA.

[15]. Sun, D., Pu, Y. X. 2005. Map Projects. Nanjing: Nanjing University Publisher.

[16]. Takano, Y., Takizawa, Y., and Sasaki, S. 2005. The SELENE project and Japanese future lunar exploreation. Acta Astronautica, 57(2-8): 112-115.

[17]. Zheng, Y. C., Ouyang, Z. Y., Li, C. L., Liu, J. Z., and Zou, Y, G. 2008. China's Lunar Exploration Program: Present and future. Planetary and Space Science, 56: 881-886.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

TEMPORAL EARTH: VISUALISING WORLD HISTORY AT ALL TIMESCALES

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ABSTRACT

A key component of Al Gore's vision for a "Digital Earth" was the ability to explore a reconstructed past at all timescales. Many academic disciplines, such as history, archaeology and geology, share the problem of depicting continuous geographic change through time and correlating different spatio-temporal phenomena. A digital earth system with such visualisation capabilities would facilitate communication among experts, act as a tool for education, and enable complex information to be displayed to the general public.

The *Temporal Earth* project aims to combine Digital Earth's universality with the flexible expressivity of animated graphics. An initial prototype, named *Sahul Time*, presents a satellite-style depiction of ancient Australasia, with coastlines changing continuously as sea levels vary throughout the Ice Age. On further layers, time-dependent icons represent habitation periods for archaeological sites, and place-names change as land masses coalesce. The 'geotagged photo' concept has been extended to become a time-dependent view of a given scene. The timeline can be zoomed in to cover the historical timescale (200 years), or zoomed out to the geological timescale (200 million years). After the age of dinosaurs, fossils are transported vast distances upon tectonic plates until unearthed by palaeontologists.

The proofs-of-concept demonstrated in the visualisation prototype are now being translated into an extended KML schema, and toolkits will be released allowing discipline experts to author their own geo-temporal representations. Ultimately, *Temporal Earth* will provide an online digital earth system through which a user can explore space and time intimately, the interface selecting appropriate resources from its database according to space/time extents and granularity.

1. INTRODUCTION

Al Gore's 1998 Digital Earth speech set an agenda for building a user-friendly interface “to put the full range of data about our planet and our history at our fingertips” [1]. Gore imagined a young girl viewing satellite imagery at multiple resolutions on a virtual globe, and choosing overlays of other georegistered data. The subsequent Digital Earth Initiative has seen much of this vision come to life through software such as *Google Earth*. But there was a second component to Gore's vision that is often overlooked:

> “She is not limited to moving through space, but can also travel through time. After taking a virtual field-trip to Paris to visit the Louvre, she moves backward in time to learn about French history, perusing digitized maps overlaid on the surface of the Digital Earth, newsreel footage, oral history, newspapers and other primary sources. ... The time-line, which stretches off in the distance, can be set for days, years, centuries, or even geological epochs, for those occasions when she wants to learn more about dinosaurs.”

Despite the prominence of historical visualisation in Gore’s original speech, comparatively little attention has been paid to this component by the Digital Earth community. While there are many examples of researchers using Digital Earth technologies to investigate and map present-day heritage, and of virtual recreations of historical sites [2], there has been less emphasis on Gore’s idea of showing historical events through time in an easy-to-use interface.

Two closely partnered projects that have previously taken up this challenge are the *Electronic Cultural Atlas Initiative* (ECAI) [3], and the *TimeMap* project at the University of Sydney [4]. However, the resulting visualisation prototypes have fallen short of delivering a really usable, scalable model for combining and delivering spatio-temporal representations. Google Earth has also introduced some temporal capabilities, but little historical content seems to have been built using these features. On longer timescales, we need visualisation paradigms capable of depicting continuous geographic change, and dealing with complex phenomena such as tectonic shifts.

In defining an overall Digital Earth system, Grossner et al. [5] suggest a return to the early prototyping efforts that were cut short in 2001. Gore himself suggested historical visualisation only as a third stage of development to be achieved “in the long run”. As we build on existing success and renew the Digital Earth vision for a new decade, it seems timely to revisit this component of Gore’s original vision.

2. THE *TEMPORAL EARTH* PROJECT

This paper introduces the *Temporal Earth* project, which aims to resolve the difficulties in visualising temporal concepts and to build a working system to turn Gore’s ideas for visualising the past into a reality. So far the project has been in a discovery phase, exploring the current temporal capabilities of existing systems (eg. *Google Earth*), but also thinking beyond these limits and developing demonstrative prototypes to a ‘proof-of-concept’ stage. The focus of the project is on time rather than global space, so it has been necessary to restrict content development to the Australasian region, with content examples selected from topics in history, archaeology and geology.

Key aims of the *Temporal Earth* project are:

- to assess the extent to which current disciplinary knowledge can be assimilated in space-time
- to investigate the utility of existing standards (eg. KML) when authoring historical content
- to develop improved visualisation methods for representing relevant temporal phenomena
- to develop proof-of-concept visualisations for various topics
- to offer design principles for Digital Earth development, and extensions to the KML standard
- eventually, to provide a platform for collaboration toward an integrated model of world history on all timescales

2.1. Historical timescale: using *Google Earth* / KML

Google Earth already incorporates some limited temporal capabilities, which set an excellent base-model for exploratory development in this project. The recent 'historical imagery' option provides a timeline to explore legacy versions of the satellite base-layer, augmented with aerial mosaics from Google's Imagery Partner Program, such as a comparison of pre-War and post-War Warsaw.

The KML-standard elements <TimeStamp> and <TimeSpan> associate a particular spatial feature with a single date or a date-range respectively. When a KML file using these elements is loaded, *Google Earth* offers a timeline that allows the user to subset such features to show only a time-slice, with an option to animate the time-slice across the timeline. This discrete model of time [6] cannot show continuously changing processes, but is nonetheless suited to many historical topics.

Google Earth has recently introduced a new element, <gx:Track> that allows an icon or model to travel from point to point over time. Although designed with GPS tracks in mind, it is equally applicable to showing the life-paths of people in history, or the provenance of artworks. In Figure 1, James Cook's first voyage is plotted as a <gx:Track>, with pages from his Endeavour Journal displayed as <ScreenOverlay> elements each associated with a <TimeStamp>.

Figure 1: James Cook's first voyage, synchronised with pages from the Endeavour Journal

2.2. Ice-Age timescale: the *Sahul Time* prototype

An early outcome of the project was a working prototype named *Sahul Time* [7], focused on showing Australia's archaeology in the context of changing geography. Taking *Google Earth* as a base-model, the strategy has been to extend its visualisation paradigms through a further dimension in time.

The choice of Adobe Flash® as a development platform offers a great advantage because its built-in animation capabilities offer a convenient way of authoring spatio-temporal content. Each graphical object in Flash has its own internal timeline, which can be partnered with Actionscript code to define its individual behaviour with respect to world-time or other attributes. Cleverly used, multiple dynamic objects can be combined to create a sophisticated expression of temporal phenomena, using time-projected animations, dynamic icons and 'epichronic symbolism' [8].

The layout of the *Sahul Time* prototype (Figure 2) is broadly similar to that of *Google Earth*, with a few key differences. The time-view is not merely a ‘time-line’ but also constitutes an expressive space which can display graphs, time period divisions or schematic diagrams. On the 100,000 year scale, the time-view shows a graph of sea-level variations, and the spatial view shows the corresponding continental geography at any chosen time. Time-aware labels indicate the different names given to these changing landmasses as they separate and coalesce.

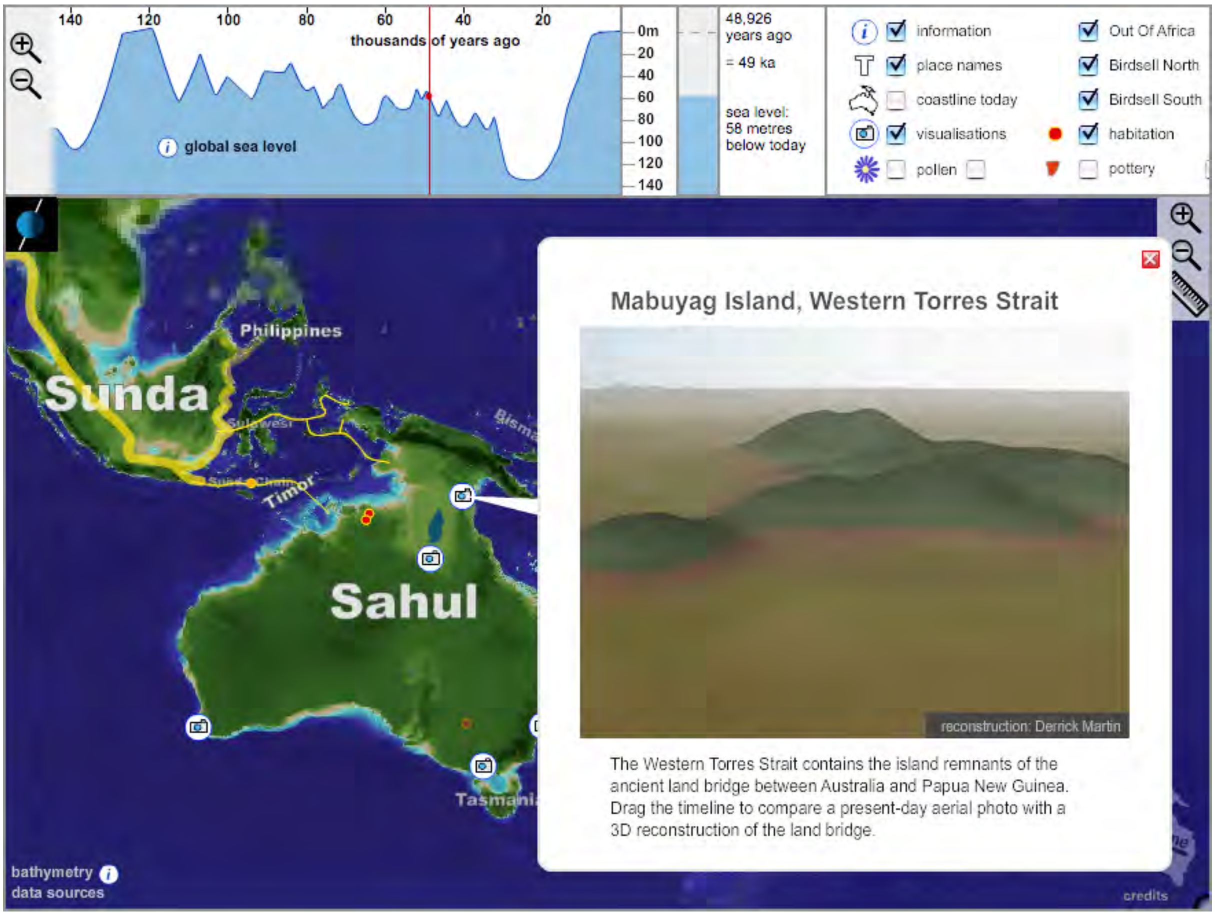

Figure 2: The *Sahul Time* prototype, showing coordinated views of Australia 50,000 years ago
Can be viewed online at http://sahultime.monash.edu.au

The red circles represent habitation sites, and each fades in and out to reflect the uncertainty in archaeological dating. Initial settlement of Sahul is believed to have occurred around 50,000 years ago, and the likely routes of arrival [9] are shown as yellow paths in Figure 2. Such an ancient date lies so far outside everyday experience that it may lack meaning for non-experts. Using *Sahul Time*, this date can be seen in comparison with other temporal landmarks such as Ancient Egypt or the Roman Empire – a mere blink of the eye by comparison.

Extending the *Google Earth* paradigm of the “geotagged photo”, *Sahul Time* can display a time-sensitive view relating to a particular location. A photo of the Torres Strait Islands is seen in the present-day but transforms into a view of the Sahul land-bridge at lower sea level. Clicking the “Devil’s Lair” archaeological site near Perth opens a section-diagram of the archaeological excavation, using carbon dates to indicate how the stratigraphic layers relate to time [10].

2.3. Simulating satellite images of the ancient past

The *Sahul Time* view above uses simple topographic shading of land masses, but some success has been made at simulating the colour of the land surface using the "climate space" concept more frequently used for environmental-niche modelling of biological species [11]. Taking a true-colour satellite image (Blue Marble 2002 [12]), screening out agricultural areas (using GLC 2000 [13]), and plotting the remaining pixels into climate space reveals a clear relationship between climate and observed land colour (Figure 3). It is hardly surprising to find that hotter, drier regions have the colour of desert sand, while warmer, wetter regions appear a forest green, and cold tundra regions have a brownish tinge.

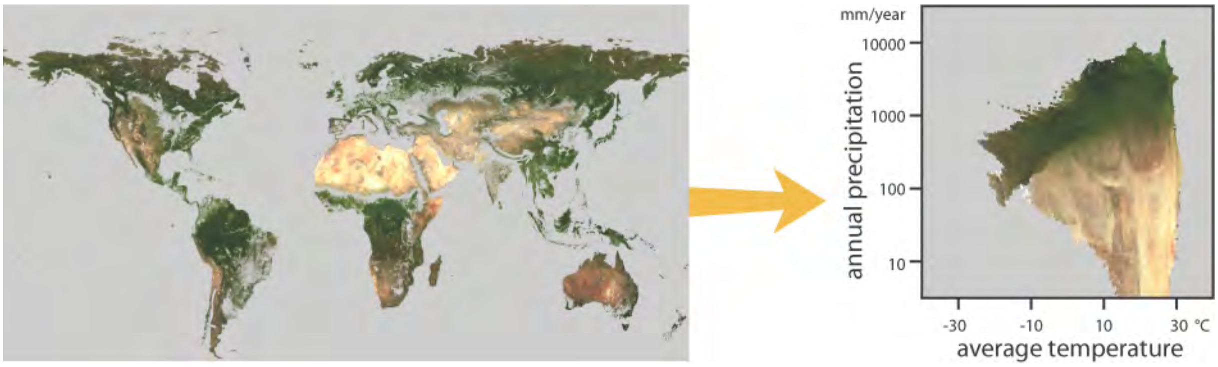

Figure 3: *Blue Marble 2002*, with agricultural land removed, and plotted into climate-space

Having established this relationship between climate and satellite colour, we have applied this climate-space colour map to a palaeoclimate model (from the Genesis 2 simulator [14]). The reconstructed image represents the photo that could be taken if a satellite could be sent back through time to the "Last Glacial Maximum", 21,000 years ago (Figure 4). The ice-sheet extents are based on Pelter's ICE-5G model [15], which also allows coastlines to be drawn that take into account the extra weight of ice on the northern continents. Lakes and glaciers within Sahul are taken from Geoscience Australia's *Palaeogeographic Atlas Of Australia* [16].

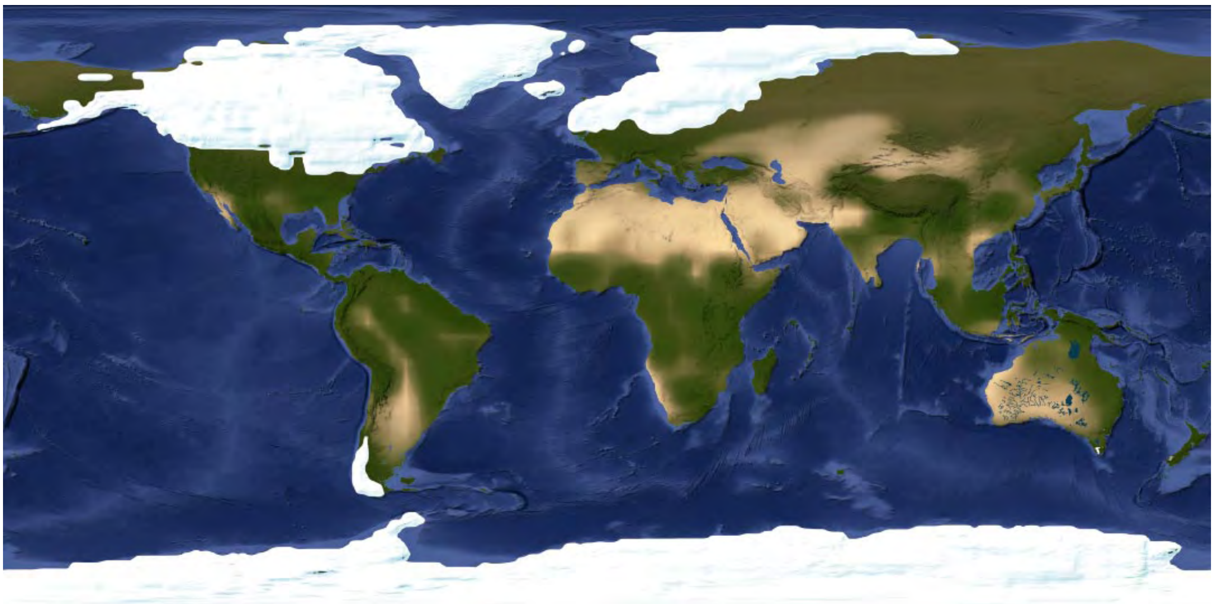

Figure 4: A simulated satellite image of the world, 21,000 years ago

2.4. Geological timescale: Dinosaurs

Just as *Google Earth*'s spatial view of the world allows the user to zoom continuously from the global to the local scale, *Sahul Time*'s time-view can be zoomed in to see historical events in greater detail, or zoomed out to view geological epochs, as suggested by Gore. On the geological timescale, the geographic view shows Ron Blakey's global palaeogeographic reconstructions, which he created by plotting data from the geological literature, then "painting the maps to look like satellite views of the Earth's past" [17].

The *Sahul Time* prototype also handles tectonic shifts using a mathematical model consisting of crustal fragments undergoing successive rotations around an axis through the Earth's centre. Present-day coastlines can be transformed into their past configurations, and icons representing dinosaur fossil sites animate along the track of their "palaeocoordinates". *Sahul Time* currently uses a flat map in geographical projection which causes major distortion close to the poles, but these visualisation principles could be equally applied to a virtual globe.

Figure 5 shows a reconstructed specimen of *Leaellynasaura amicagraphica*, a dinosaur that lived around 115 million years ago on the Gondwanan supercontinent, very close to the South Pole [18]. The balloon-view shows a time-dependent view of the rift valley that formed as Australia began to separate from Antarctica. As the user scans forward through the timeline, Australia finally breaks away and drifts northward with its fossil cargo on board. The *Leaellynasaura* fossil was unearthed in the 1980s at Victoria's "Dinosaur Cove" by palaeontologists Tom Rich and Pat Vickers-Rich [19].

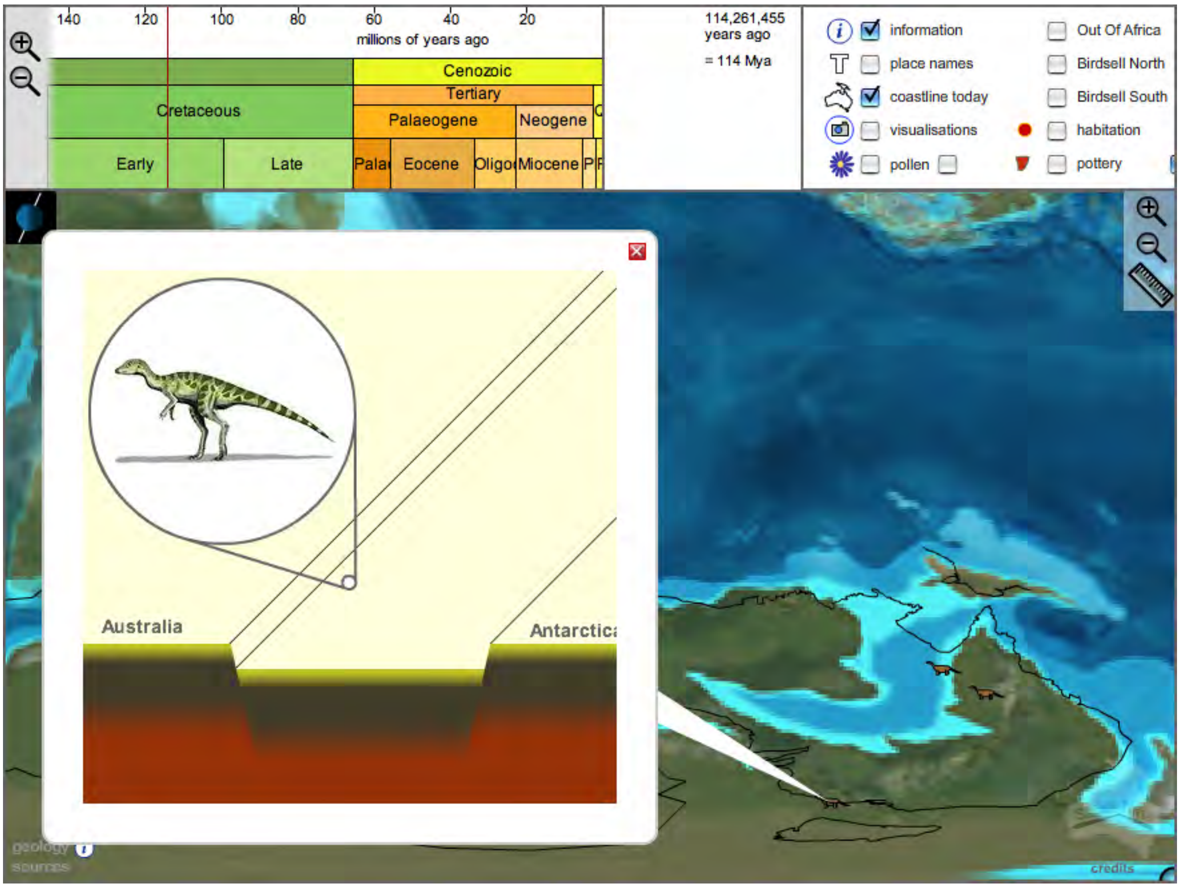

Figure 5: *Leallynasaura* inhabiting the rift-valley as Australia breaks away from Antarctica

2.5. Extending the KML schema

Building on the *Google Earth* / KML base-model, the ideas emerging from this project are being codified into robust extensions to the KML language, using the tx: namespace prefix to identify them as *Temporal Earth* extensions. To maintain inter-operability, these enhancements have been designed to "degrade gracefully" when loaded into *Google Earth*, providing a functional, but less sophisticated representation. Over time, it is hoped that some of these suggestions might be implemented into *Google Earth*, and that some might ultimately find their way into the KML standard.

Among the KML extensions so far identified:

- <tx:beginFade> and <tx:endFade> give <TimeStamp> and <TimeSpan> some fuzziness
- a <tx:AnimatedIcon> will synchronise its own timeline with world-time
- a <tx:DynamicIcon> will change its appearance in response to <ExtendedData> values
- a <tx:fragment> attribute will attach a KML Feature to a tectonic crustal fragment's movement
- a <tx:TimelineOverlay> is superimposed onto the time-view, spanning a specified date-range
- a <TimelineStyle> will dictate how a Feature's temporal footprint is depicted in the time-view
- a <tx:TimeRegion> will regulate a Feature's visibility according to timescale and time window

3. AN AGENDA FOR FUTURE DEVELOPMENT

The *Sahul Time* prototype has so far provided a very effective research tool for exploring visualisation possibilities, and exemplifies some compelling applications of historical visualisation. However, its technical capabilities are not sufficiently scalable, and a new cycle of development is warranted, informed by the discovery process already undertaken using *Sahul Time*.

3.1. Building *Temporal Earth*

"*Temporal Earth*" has been selected as an appropriate name to launch a renewed project at the full scope envisaged by Gore. The major components of *Temporal Earth* will be:

• formalising visualisation enhancements and KML extensions with appropriate documentation
• a repository to serve resources appropriate to particular space/time extents and granularity
• developing a robust, explorable spatio-temporal visualisation client
• a means to author an extensive collection of resources across all regions and timescales

From the user perspective, the final system should provide a top-down, intuitive exploration of space and time, allowing them to seamlessly browse different spatial and temporal extents and 'discover' content of an appropriate level of detail. Just as *Google Earth* offers different levels of abstraction in layers such as roads and borders, *Temporal Earth* must take into account temporal granularity, particularly as many phenomena have a cyclical component with widely varying periodicity.

Prototype development continues, using the Google Earth API and Javascript to develop a browser-based interface, to build extra functionality on top of *Google Earth*'s native capabilities. TimeMap has already had some success interfacing the Google Maps API with MIT's *SIMILE* timeline widget [20]. The repository may take a form similar to the ECAI Clearinghouse, a central server acting as a gateway to many resources distributed across the Web. Web Feature Service (WFS) offers an appropriate format for querying such a repository, with KML objects returned as the response payload.

3.2. Populating *Temporal Earth*

Authoring sufficient content for Temporal Earth is a considerable challenge, given the daunting quantity of data about the Earth's past, along with the alternative interpretations offered by different experts. Wikipedia has proved an effective means of combining user-editable articles with opportunities for discussion and collaboration, toward a consensus-based representation. Many explorers' journals are now being digitised on WikiSource, and an allied crowd-sourcing project could allow the corresponding explorers' paths to be drawn from maps, animated through time and cross-referenced with the journals, as shown in the Endeavour example above.

More complex phenomena will require far more sophisticated dynamic representation, which can only be achieved using advanced software. Flash has proved a very effective tool for authoring content into *Sahul Time*, and remains the most user-friendly method available for authoring dynamic graphics. But while Flash animations have become ubiquitous on the web, the Flash software remains proprietary, and its low-bandwidth *swf* files are only a semi-open format, unsupported by software such as *Google Earth*. By comparison, Google provides the 3D software *SketchUp* to allow anyone to model city buildings and upload them into *Google Earth*. If appropriate free software were available, a similar crowd-sourcing initiative might digitise maps and other historical resources to produce spatio-temporal representations such as historical empires growing and declining.

At longer timescales, reconstructing ancient geography is rather like a 4-dimensional jigsaw puzzle with the pieces spanning vastly differing spatial and temporal scales. But *Google Earth*'s imperfect integration of satellite and aerial imagery shows that even if the pieces don't fit together perfectly, the result may be acceptable and informative to the viewer. Development on this timescale may be reserved for the experts, with an associated peer-review process. Elsevier's GeoFacets [21] provides a vast database of geological maps from its journal archives, geo-registered onto the globe, and made searchable via an interactive map. Ideally, *Temporal Earth* requires assimilation of such knowledge into a standardised, readily understandable form, such as the 'simulated satellite imagery' above.

Gore imagined that Digital Earth would become a "collaboratory" for researchers, and it is often the case that the outputs of one research area become the inputs for another. Elsevier's *Article Of The Future* project is investigating how new communication modes such as digital globes could become part of the scientific discourse.

4. CONCLUSION

Al Gore's vision of Digital Earth set a Grand Challenge [22] "to put the full range of data about our planet and our history at our fingertips". While it has been largely overlooked in current efforts, the dimension of deep-time is a vital component in that goal. It is a key tenet of geology that the present is the key to the past, and the past is the key to the future, a principle particularly significant as we face challenges such as climate change. The Digital Earth concept has fostered a revolution in the ways we can access, view and understand spatial information, and it has the potential to do the same for the world's history. The Temporal Earth project hopefully offers a start in that direction.

The *Sahul Time* project gratefully acknowledges support from the Environmental Futures Network. Thanks also to Tim Denham as PhD supervisor, Ruth Jelley and Ian Coller for proofreading drafts of this paper.

REFERENCES

[1] Gore A.: *The Digital Earth: Understanding our planet in the 21st Century*. Speech to the California Science Center, January 31, 1998

[2] Wells S., Frischer S., Ross D., Keller C.: Rome Reborn in Google Earth. *Making History Interactive. 37th Proceedings of the CAA Conference* March 22-26, 2009, Williamsburg, Virginia pp.373-379. Archaeopress: Oxford. (2010).

[3] Buckland M.: The Electronic Cultural Atlas Initiative: Ten Years Experience with Geo-Temporal Resources. *5th International Symposium on Digital Earth*, Berkeley, 2007.

[4] Johnson I.: Putting Time on the Map: Using TimeMap™ for Map Animation and Web Delivery. *Geoinformatics*, July-August 2004, pp.26-29;

[5] Grossner K., Goodchild M., Clarke K.: Defining a Digital Earth System. *Transactions in GIS*, Vol. 12(1), pp.145-160 (2008).

[6] Wachowicz M.: *Object-oriented design for temporal GIS*. Taylor & Francis, 1999.

[7] Coller M.: SahulTime: Rethinking Archaeological Representation in the Digital Age. *Archaeologies: Journal of the World Archaeological Congress*. (2009)

[8] Shepherd I.: Putting time on the map: dynamic displays in data visualisation and GIS. In Taylor, P. (ed) *Innovations in GIS 2*. Taylor & Francis, London, 1995.

[9] Mulvaney J., Kamminga J.: *Prehistory of Australia*. Allen and Unwin, London, 1999.

[10] Dorch C.: Devil's Lair, an Example of Prolonged Cave Use in South-Western Australia. *World Archaeology,* 10(3), pp.258–279 (1979)

[11] Porch N.: Climate space, bioclimatic envelopes and coexistence methods for the reconstruction of past climates: a method using Australian beetles and significance for Quaternary reconstruction. *Quaternary Science Reviews*, Vol. 29, pp.633–647 (2010)

[12] NASA: The Blue Marble: Land Surface, Ocean Colour and Sea Ice. Available: http://visibleearth.nasa.gov/

[13] European Joint Research Committee: Global Land Cover 2000. Available: http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php

[14] National Center for Atmospheric Research, Pennsylvania State University: PMIP Documentation for GEN2. Available: http://pmip.lsce.ipsl.fr/docs/gen2doc.html

[15] Peltier W.: Global Glacial Isostasy and the Surface of the Ice-Age Earth: The ICE-5G (VM2) Model and GRACE, *Ann. Rev. Earth and Planet. Sci.,* Vol. 32, pp.111-149. (2004)

[16] Geoscience Australia: Palaeogeographic Atlas of Australia (CD-ROM) 2001

[17] Blakey R.: Global Paleogeographic Maps. Colorado Plateau Geosystems, Inc. Available: http://cpgeosystems.com/

[18] Rich, T.H. Significance of polar dinosaurs in Gondwana. Memoirs of the Queensland Museum 39:711-717.

[19] Rich, T.H. 1996 Significance of polar dinosaurs in Gondwana. Memoirs of the Queensland Museum 39:711-717.

[20] Huynh, D.: SIMILE Widgets | Timeline. http://www.simile-widgets.org/timeline/

[21] Elsevier: GeoFacets. http://geofacets.com

[22] Goodchild, M.: Geographic Information Science: The Grand Challenges. In Wilson, P., Fotheringham, S.: The Handbook of Geographic Information Science. Wiley 2008.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

PERFORMANCE OF DEM GENERATION TECHNOLOGIES IN COASTAL ENVIRONMENTS

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ABSTRACT

A prerequisite to quantitative assessment of risks to coastal zone communities, infrastructure and natural systems posed by sea level rise associated with climate change is the provision of high-resolution Digital Elevation Models (DEMs) to form a basis upon which hydrological models are built. This paper reports upon the outcomes of a project that has investigated the performance of different DEM generation technologies within coastal environments in Eastern Australia. The accuracy of DEMs produced from LIDAR, airborne IFSAR, digital aerial imagery and SPOT5 satellite imagery have been investigated, along with the 1-second SRTM DEM and a DEM derived from 1:25,000 map data. The LIDAR DEM was taken as the master data set against which the others were assessed, the absolute accuracy of the LIDAR having first been evaluated via a vehicle-borne kinematic GPS survey and a check against data from permanent survey marks. In many respects, the results obtained in the project reinforce known performance characteristics of the different DEM generation technologies. However, the project also highlighted other relevant characteristics, for example the issue of systematic elevation biases and distinctions between technologies when the required filtering from the visible-surface DSM to the bare-earth DEM relies solely upon automated land cover classification. These and other aspects of the project outcomes will be discussed in order to provide a better insight in DEM generation performance in low-lying coastal areas of different land cover, ranging from urban to dense forest.

1. INTRODUCTION

Some 85% of Australia's population lives within 50km of the coast, with much of the area covered by our coastal cities and towns lying below an elevation of 10m. A prerequisite to quantitative assessment of risks to coastal zone communities, infrastructure and natural systems posed by sea level rise associated with climate change is the provision of accurate terrain models, both topographic and bathymetric. On the topographic side, there is a need for high-resolution digital elevation models (DEMs), and in cases digital surface models (DSMs), as a basis upon which to build hydrological models that provide the inundation scenarios needed for risk analysis. Nowadays, technologies for DEM generation range from airborne laser scanning, or LIDAR, through to airborne and space-borne stereo photogrammetry and interferometric synthetic aperture radar (IFSAR). The vertical accuracy and horizontal resolution provided by these technologies can routinely range from the typical 10-15cm and 4 points/m^2 level of LIDAR, and also aerial photogrammetry, through to the 8-15m accuracy and 30m grid spacing of the national 1-second SRTM-based DEM, which was derived from IFSAR data from the Shuttle Radar Topographic Mission. In relation to DEMs, it is well understood that the cost of generation is directly proportional to resolution. In the context of provision of coastal zone DEMs, the question then arises as to the optimal approach to cover the most vulnerable areas of Australia's 27,000km coastline at the required resolution, which varies based on vulnerability.

Under the auspices of the program *Urban Digital Elevation Modelling in High Priority Regions Program, Phase 2* (UDEM2) of Australia's federal Department of Climate Change and Energy Efficiency, the Cooperative Research Centre for Spatial Information (CRCSI) recently conducted an investigation into DEM generation in coastal zone environments. The objective of this project was to evaluate the performance of different DEM technologies, recognizing that the quality of bare-earth DEMs is a function not only of the data acquisition and subsequent data processing, but also of the topographic and land cover characteristics of the terrain being modelled. DEMs produced from different imaging and ranging sensors need to be analysed in order to better understand their characteristics and accuracy, and also their cost-benefit ratios in relation to fulfilling the need for fit-for-purpose elevation models for coastal assessments. The focus of the DEM performance project conducted was upon detailed assessments of the overall accuracy produced by six DEM generation technologies within test areas representing typical low-lying eastern Australian coastal environments, with land cover types including urban, rural and forest. Outcomes of the project were intended to provide an increased understanding of the characteristics and performance of different elevation data technologies. Results could thus inform the development of guidelines covering optimal DEM generation technologies for vulnerable coastal zones.

2. DEM TECHNOLOGIES

The six technologies considered were LIDAR, airborne IFSAR, SPOT5 HRS satellite imagery, the newly released 1-second SRTM-based national DEM, and aerial photography. In the aerial photogrammetry category, the DEM data was sourced from existing 1:25,000 digital topographic mapping, and from ADS40 digital aerial imagery with 50cm GSD. Each DEM generation technology has well recognized attributes and limitations. In this investigation, however, the aim was to look beyond known differences in vertical resolution, cost and productivity, and to consider overall performance. Of the DEMs sourced for the project, those from LIDAR, ADS40, airborne IFSAR and topographic map data (here termed Topo DEM) were made available by LPMA (NSW Dept. of Lands), and Geoscience Australia supplied the SPOT5 and SRTM DEMs. It was initially planned to also consider ALOS PRISM and TanDEM-X DEM data, but this was unavailable at the time. The post spacings of the gridded DEM data, and the nominal vertical accuracy for each technology was as follows: LIDAR, 2m grid, 15cm vertical accuracy; SRTM, 30m, 8-15m; SPOT5, 30m, 8-10m; IFSAR, 5m, 1m; ADS40, 8m, 1m; and Topo DEM, 25m, 3m. Within the respective DSM-to-DEM conversions, the LIDAR, IFSAR, SRTM and Topo DEMS had been subjected to manual classification and editing, and were supplied as fully bare-earth DEMs. The SPOT5 and ADS40 elevation models, on the other hand, were subjected only to automated classification and filtering and are considered smoothed DSMs, especially in densely forested areas.

3. TEST AREA LOCATIONS

Two criteria governed selection of geographic location for the DEM analysis: 1) suitability in the context of overall assessment of coastal zone vulnerability to climate change; and 2) availability of DEM coverage. Within the chosen area, the mid north coast of New South Wales, where there had been recent production of medium- and high-resolution DEMs from airborne IFSAR, LIDAR and photogrammetry (from ADS40 aerial imagery), and there was existing coverage from SRTM, 1:25000 topographic mapping and SPOT5 HRS data.

Following the selection of the general test area based on data availability, it was necessary to select specific test sites, which in combination fulfilled the following requirements:

- Coastal zone with mixed vegetation, ranging from grassland to scrubland and forest.
- Topographic variation, ranging from floodplains to undulating low-level coastal sand dunes.
- Variation in land cover, from urban to rural to bushland and forests.
- Contain extensive areas below 10m elevation and open to the coastline.

One aim of the project was to assess the influence of both man-made structures in an urban environment, and different land and vegetation cover, on the accuracy and integrity of bare-earth DEMs. Although there have been a number of published reports on the performance of DEM generation technologies in different topography [1-5], the impact of ground slope was not analysed in detail in this project. The reasons for this were, firstly, that by its very nature the vulnerable coastal zone is low-lying, with only mild topographic variation; and, secondly, the metadata necessary to comprehensively consider slope and aspect for the IFSAR, ADS40 and LIDAR data were not available. The analysis was thus limited to gridded DEM data only. Moreover, most of the analysis was restricted to areas with an elevation below 10m, ie to the areas most vulnerable to inundation.

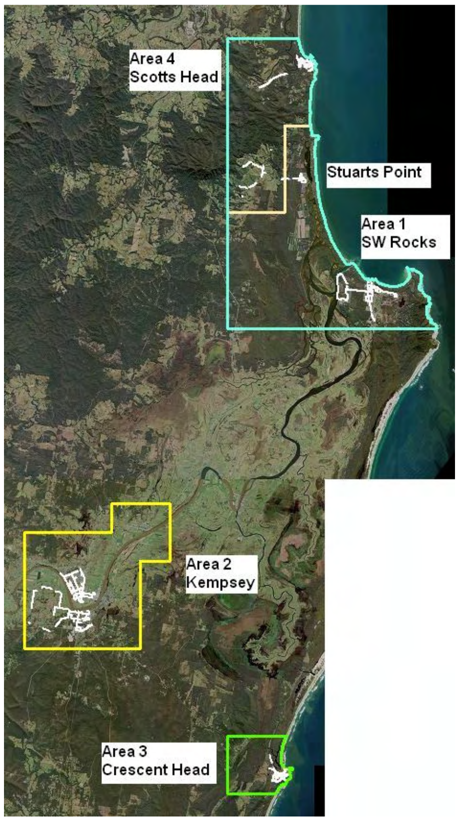


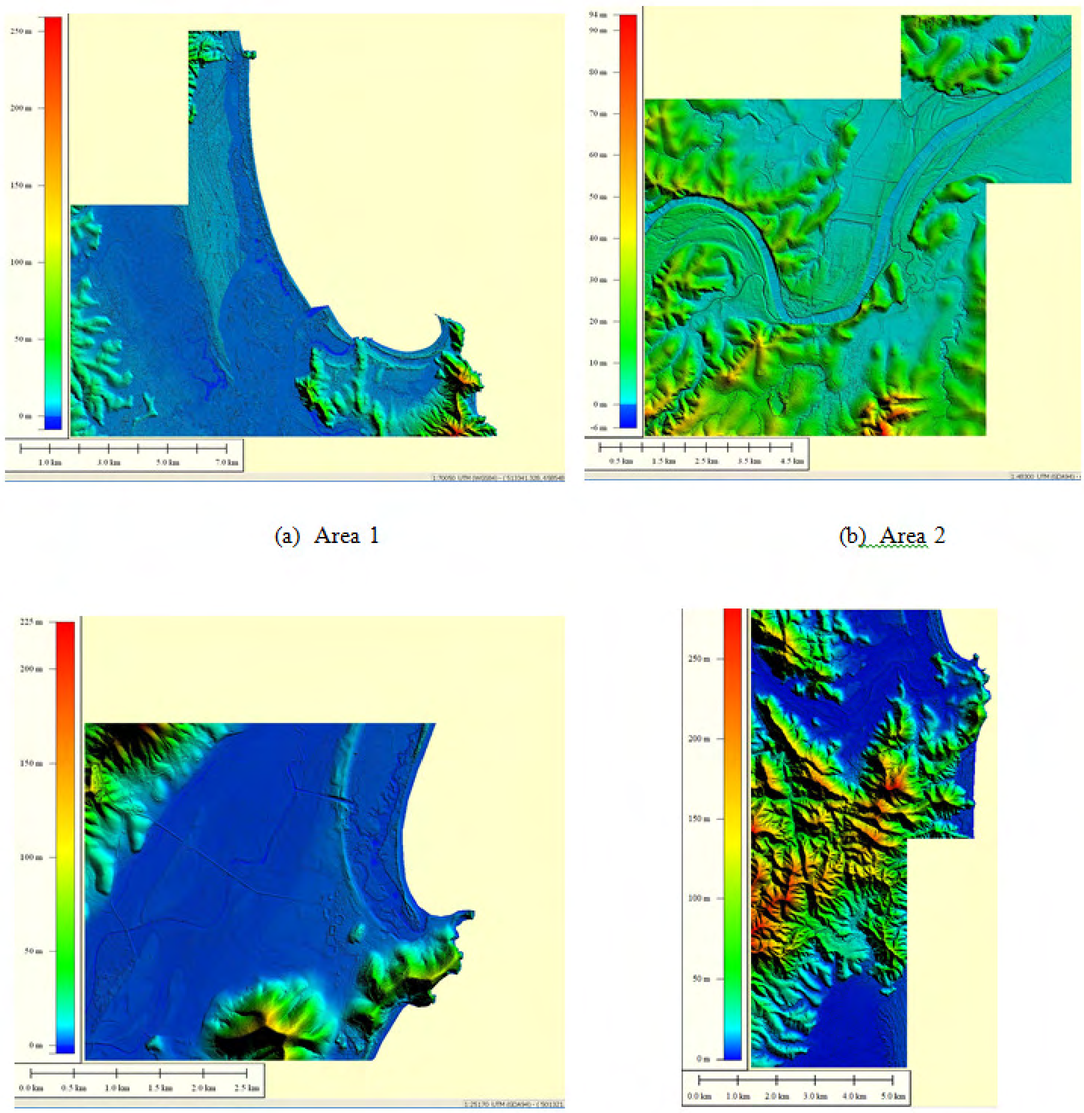
Figure 1: Four test areas in NSW and elevation profiles recorded by kinematic GPS.

Shown in Figure 1 are the four selected test areas: Area 1 (128 km^2) extends from South West Rocks to the Stuarts Point area and comprises varied coastal topography and vegetation cover. Area 2 (76 km^2), which is centred on the town of Kempsey, constitutes the sample low-lying urban area. Area 3 (24 km^2) covers Crescent Head and this was selected based on the varying terrain of the headland. Area 4 (72 km^2) was added to the initial three in order to provide further coverage of both dense coastal forest areas, and an additional urban area, namely the settlement of Scotts Head. The DEMs for each of the test areas are shown in Figure 2.

4. ANALYSIS

4.1. Datum Issues

The initial step in the accuracy assessment and analysis of the DEMs of varying resolution involved the bringing of all datasets into a uniform reference coordinate system. Current DEM data acquisition technologies utilize GPS for absolute positioning and consequently the DEM is initially referenced to the WGS84 ellipsoid. A height conversion from ellipsoidal to orthometric is then carried out using both geoid height information and, where applicable and if known, the local relationship between the AusGEOID09 geoid model and the Australian Height Datum (AHD).



(a) Area 1 (b) Area 2 (c) Area 3 (d) Area 4

Figure 2: DEMs for four test areas.

In the conversion of height data recorded in the kinematic GPS survey conducted as part of the project, AusGEOID09 was employed to facilitate a one-step WGS84-to-AHD vertical datum conversion. It is noteworthy that there can be discrepancies in actual ‘local’ mean sea level (MSL) and AHD amounting to 70cm or more as a consequence of sea-surface topography. However, localized distortions in AHD do not have a significant impact in the present accuracy analysis for two reasons. Firstly, height differences are being determined, which nullifies the effect of absolute biases in the datum, at least when all DEMs are nominally referenced to AHD. Secondly, the anticipated local MSL versus AHD biases can be anticipated to be small in relation to the overall error budget for all DEM data other than the LIDAR DEM.

4.2. Benchmark Elevation Data

The reference elevation model against which DEMs from different data sources were to be compared was the LIDAR DEM. In order to assess the quality of this 'standard' against ground survey data that is directly referenced to AHD, surveyed benchmark data within the test areas was accessed, and a vehicle-borne kinematic GPS survey was performed. The use of heights from permanent survey marks was primarily in order to ascertain whether there was any local bias in the AHD reference system not modeled via AusGEOID09. Agreement between benchmark heights and the LIDAR DEM was at the level of 13cm RMS, but there were only nine accessible benchmarks. To supplement the ground surveyed checkpoints, a vehicle-borne kinematic GPS survey was performed in which 27000 points were measured to an accuracy of 2 – 4cm. The measured profiles along approximately 120km of road, shown in Figure 1, were mainly restricted to in and around townships where there was less tree cover along the roads. In assessing the height discrepancies between the GPS and corresponding points from the LIDAR DEM, it should be kept in mind that given the 2-3cm accuracy of the laser ranging component, and the fact that both data sets were transformed from ellipsoidal to orthometric heights via the AusGeoid09 geoid model, elevation differences will be primarily a function of discrepancies in the GPS surveying of platform positions, airborne and terrestrial; and errors in the filtering of the LIDAR data, ie in the removal of above bare-ground features.

In many respects the comparison of elevations along roadways would be expected to yield optimal results, since issues with filtering are minimized. However, in the case of the test areas considered, there were instances were roadside vegetation appeared to adversely influence filtering performance. Nevertheless, after removal of outliers (4% of the 27,120 GPS positions), the overall RMS height discrepancy value was 0.11m, which validated the integrity of the LIDAR data, as far as was practicable, and was consistent with LIDAR accuracy specifications.

4.3. Analysis of DEMS against LIDAR Reference Data

Table 1 lists results from initial comparisons of DEMs against the LIDAR 'standard', for each DEM technology. The comparisons were restricted to areas of 10m elevation or less, these being deemed most vulnerable to the impact of rising sea level. The results present a summary of accuracy in the test areas, as quantified by both the Root Mean Square height discrepancy/Error value (RMSE) and the estimated standard error ($\sigma_{\Delta h}$), both being relative to the LIDAR DEM. The distinction between these two measures is that the RMSE includes the error arising from systematic height biases, whereas the $\sigma_{\Delta h}$ is free of the overall mean bias. Thus, $\sigma_{\Delta h}$ is always equal to or smaller than the RMSE.

Also listed in the table are the percentages of points removed from the analysis as outliers, the magnitude of their discrepancy values being in excess of the listed thresholds. The higher the percentage, the 'noisier' the DEM. The area that was most noise-free, as expected, was Area 2 and the ADS40 'DEM' (actually smoothed DSM) constituted the noisiest data. Some 40% of ADS40 data points in Area 4 were classed as outliers, which is no doubt attributable to incomplete classification and filtering within forested areas. Due to the restriction of the analysis to elevations of less than 10m, there is limited initial consideration of DEM performance within urban environments, since most of the town of Kempsey, as well as significant parts Southwest Rocks, Crescent Head and Scotts Head, all lie at elevations above 10m. DEM performance in urban areas is touched upon in a later section.

Table 1. Accuracy evaluation result. Only height differences against LIDAR reference DEM below listed thresholds are included and those above are removed, as per the %-removed column.

Dataset (Rejection Threshold)	Height bias (m)	RMSE (m)	$\sigma_{\Delta h}$ (m)	Sample Size	% removed
SRTM DEM, Area1 (15m)	0.5	3.4	3.4	85740	0.06
SRTM DEM, Area 2 (15m)	-0.6	2.2	2.1	51625	0.03
SRTM DEM, Area 3 (15m)	1.9	4.1	3.6	13075	0
SRTM DEM, Area 4 (15m)	2.4	4.3	3.6	20927	0.8
SPOT5 DEM, Area 1 (15m)	4.3	5.1	2.8	79077	7.8
SPOT5 DEM, Area 2 (15m)	4.3	4.7	1.9	51443	0.4
SPOT5 DEM, Area 3 (15m)	4.8	5.5	2.8	12359	5.5
SPOT5 DEM, Area 4 (15m)	5.3	6.0	3.0	18962	10.1
Topo DEM, Area 1 (10m)	0.8	2.3	2.2	123454	0.01
Topo DEM, Area 2 (10m)	2.0	3.3	2.7	74354	0.02
Topo DEM, Area 3 (10m)	2.5	3.2	1.9	18906	0.1
Topo DEM, Area 4 (10m))	1.4	2.6	2.2	30377	0.2
IFSAR DEM, Area 1 (5m)	0.0	1.4	1.4	3038739	2.0
IFSAR DEM, Area 2 (5m)	0.1	0.8	0.8	1855859	0.3
IFSAR DEM, Area 3 (5m)	0.4	1.1	1.0	473092	0.7
IFSAR DEM, Area 4 (5m)	0.3	1.5	1.5	701487	8.7
ADS40 DSM, Area 1 (5m)	0.8	1.9	1.8	852493	29.5
ADS40 DSM, Area 2 (5m)	0.3	0.9	0.9	695044	4.4
ADS40 DSM, Area 3 (5m)	0.9	1.7	1.4	116038	37.6
ADS40 DSM, Area 4 (5m)	0.6	1.6	1.5	179993	39.9

The results in Tables 1 reveal a number of characteristics, some unique to particular DEM data acquisition technologies and others common to all. In the latter category, findings could be briefly summarizes as follows:

- The accuracy associated with each DEM technology, as assessed via the RMSE and $\sigma_{\Delta h}$ values was basically consistent with or better than suggested by specifications. In the case of the SRTM data the RMSE values of around 2 - 4m were significantly lower than anticipated, whereas the standard error of the SPOT5 DEM displayed lower than expected standard error values of 2 - 3m, but also a disturbing, persistent height bias of close to 5m. The accuracy of the Topo DEM was close to specifications, namely around 3m, whereas the IFSAR and ADS40 DEMs displayed an accuracy level in the range of 0.7m to 1.5m, which is equal to or slightly below expectations.
- As anticipated, both height biases and RMSE values are generally larger for Areas 1, 3 and 4 than for Area 2. The lack of forest cover in the open floodplain area around Kempsey accounts to a large degree for this characteristic, since the positive bias effect of the DEM being in reality more of a canopy DSM in forest areas is absent. It can be seen that the bias and RMSE values follow this trend for the SRTM, IFSAR and ADS40 DEMs, but not for the SPOT5 and Topo DEMs. In the case of the SPOT5 DEM there is a relatively uniform bias of 4-5m across all three areas.
- Also as anticipated, the distribution of RMSE values and standard errors for each technology is correlated to the presence or absence of forest. There should be an expectation that automated

DSM-to-DEM conversion will yield better results for IFSAR versus photogrammetrically derived DEMs generated through image matching because of the ability of radar to partially penetrate vegetation. It is noteworthy that the mean biases for the SRTM and airborne IFSAR DEMs are 0.9m and 0.3m, respectively. In the case of the Topo DEM, where extensive manual filtering had been carried out, the systematic errors in DEM heights, although influenced by the presence of forest, tend to be concentrated in a small number of areas, as opposed to being distributed widely throughout forested regions.

4.4. Performance of DEM Technologies

Based on results obtained, the following general summaries of DEM accuracy are offered:

SRTM DEM. The achieved RMSE, standard error (1-sigma) and mean height bias values are very impressive. Instead of finding an RMSE close to 10m, the values range from 2.2m for Area 2 to 4.3m for the heavily forested Area 4. The corresponding 1-sigma values are 2.1m and 3.6m. At a 15m, or approximately 4-sigma outlier rejection threshold, the number of rejected points falls below 1% and height blunders exceeding 15m are confined to a small number of local vegetation clusters in Area 4. The main conclusion regarding the GA-supplied 1-second STRM DEM is that within the coastal areas considered it is more accurate than specifications would suggest.

SPOT5 DEM. With a point rejection threshold of 15m, the resulting standard errors for the SPOT5 DEM were 3m or just under in Areas 1, 3 and 4, and just below 2m in Area 2. This is well within specifications. Of concern, however, is the significant height bias of 4 - 5m in all four test areas, which results in RMSE values ranging from 4.7 to 6.0m. One can only speculate as to the cause of the systematic height error. For example, it is could arise in large part in this case from errors in the exterior orientation of the stereo satellite imagery, perhaps as a consequence of insufficient or inaccurate ground control within the block adjustment process. Alternatively, it might be attributable to shortcomings in the filtering of vegetation within the DSM-to-DEM conversion. The latter assumption is supported to some degree by the percentages of the rejected points where the height error exceeded a 15m threshold, there being over 8% in Area 1, 6% in Area 3, 10% in Area 4, and a predictably lower 0.4% in Area 2, which is largely devoid of forest cover. The rejected points are concentrated mainly in areas of dense coastal forest.

Topo DEM. The vertical accuracy specification typically associated with 1:25,000 topographic mapping is 3m, corresponding to a third of the contour interval of 10m. Initial expectations for the Topo DEM would then be an RMSE at the 3m level, with localized occurrences of height biases as opposed to the area wide bias seen in the SPOT5 DEM. The mean height biases obtained for the Topo DEM, with a 10m rejection threshold, were 0.8m in Area 1, 2m in Area 2, 2.5m in Area 3 and 1.4m in Area 4. While the biases in Areas 2 and 3 are higher than one would anticipate for a 3m-accurate DEM, they are not viewed as significant given the corresponding 1-sigma values, which had a range of 1.9 - 2.7m. The number of points with height discrepancies greater than the 10m cut-off (nominal 3-sigma value) was 0.2% or less for all four areas. This is consistent with the expectation that the Topo DEM should have fewer filtering errors because of the map compilation process being based on manual stereoplotting from aerial photography.

Airborne IFSAR DEM. With the relatively coarse rejection threshold value of 5m or approximately 5-sigma assigned to the airborne IFSAR DEM, resulting RMSE values were 1.4m in Area 1, 0.8m in Area 2, 1.1m in Area 3 and 1.5m in Area 4. The corresponding $\sigma_{\Delta h}$ values were basically the same as a consequence of the modest bias values of 0.5m or less. Unlike the three lower resolution DEMs discussed above, which exhibited accuracy well within specifications, the IFSAR DEM displayed an accuracy that was generally consistent with expectations but a little worse than anticipated. Regarding the %-removal values, the areas shown in red and blue in Figure 3 indicate where the height discrepancy values exceeded the assigned thresholds, these being 3m (red) and 5m (blue) for the case of airborne IFSAR. The regions with most rejected points corresponded to hilly terrain with steeper slopes, and to a lesser extent to forested areas.

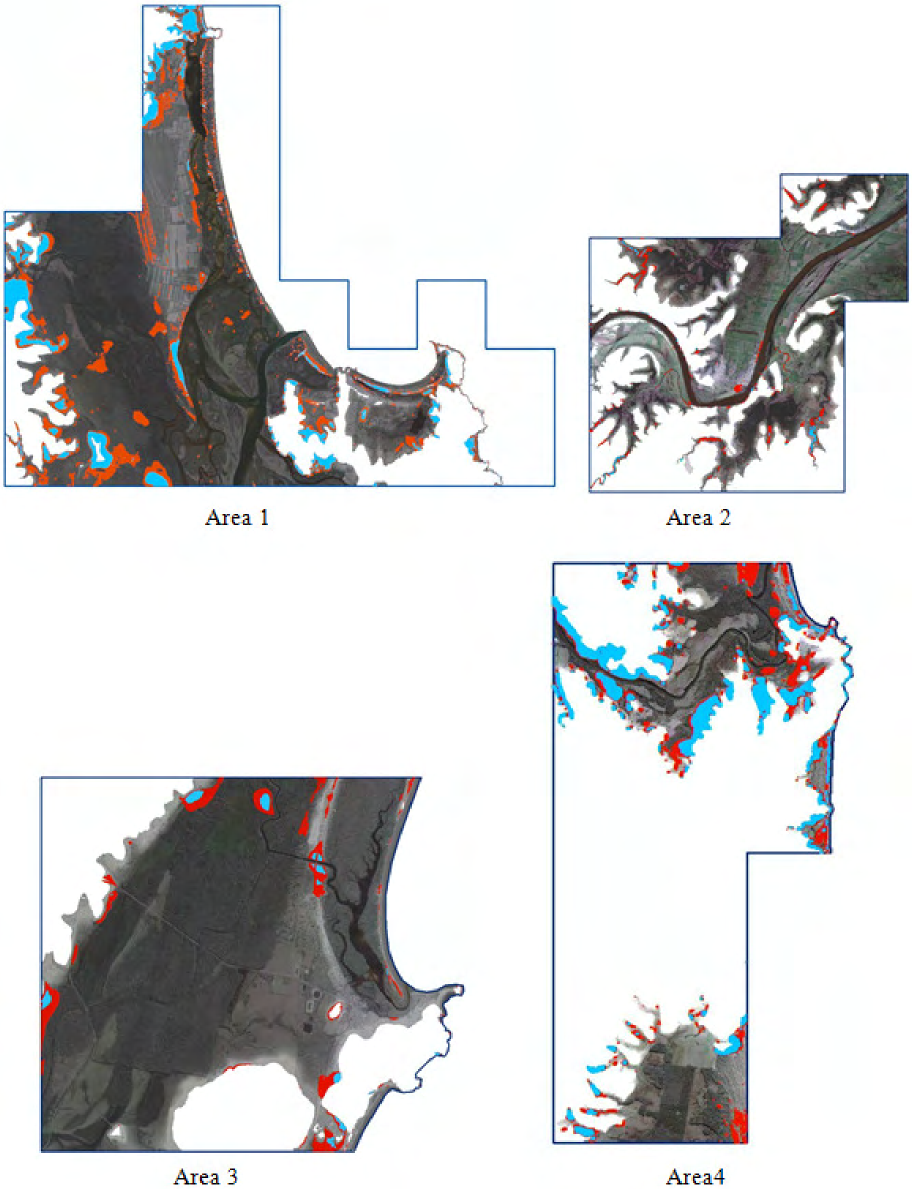


Figure 3: Points within the airborne IFSAR DEM with height discrepancies greater than threshold values when compared to the LIDAR reference DEM. Red areas representing a 3m threshold are overlaid by blue areas representing a 5m cut-off (areas not to scale).

ADS40 DEM. The 'DEM' derived from ADS40 digital 3-line scanner aerial imagery was in actual fact a 'smoothed' DSM that had undergone some initial automated classification and filtering. The partial filtering of the ADS40 DSM is indicated by the majority of elevations within forested areas being rejected as outliers, their associated discrepancy values against the LIDAR data being greater than 5m or roughly 5-sigma. Some 40% of the discrepancy values in Area 4 were rejected. The assumption that the RMSE values were inflated by an incomplete DSM-to-DEM conversion is reinforced by the results of forest-free Area 2, where the RMSE value for the 5m threshold falls from the near 2m level of Areas 1, 3 and 4 to 1m, and the %-removal value drops from 30% or more to 4%. Given the incomplete filtering, it is difficult to characterise the accuracy of the ADS40 elevation data, but it is encouraging to see results in Area 2 which are consistent with accuracy specifications.

5. IMPACT OF LAND COVER

Based on the results obtained in the analysis of performance of the five DEMs against the LIDAR reference DEM, it is apparent that a significant factor limiting accuracy in the generation of supposedly bare-earth DEMs is automated classification and filtering in forest and urban areas, with vegetation cover appearing as a more significant issue than the presence of buildings. In order to gain further insight into the impact of different land cover on the DEM technologies considered, analyses were carried out for samples of specific land cover types of urban, forest/bushland and open farm land. Once again, elevation bias, RMSE and standard error of height discrepancies were quantified using the LIDAR data as the reference DEM. The results of this phase of the performance evaluation are briefly touched upon in the following paragraphs; further details are provided in [6].

Three 'urban' test areas were selected, two residential, and the commercial centre of South West Rocks. In terms of accuracy, the RMSE values obtained were largely consistent with those obtained in the full-area evaluations. However, the height bias for the SRTM and SPOT5 DEMs increased over that listed in Table 1, reaching 6-7m for the SPOT5 DEM. The results achieved for the three urban areas for the Topo, IFSAR and ADS40 DEMs show an overall reduction in height bias, which is indicative of a successful filtering of buildings in the automated DSM-to-DEM conversion process.

The three sample rural sites comprised an area of open grassland with thinly distributed houses and trees in West Kempsey, and open and ploughed fields near Stuarts Point. The results of the analysis for these test areas highlighted that when the need for extensive filtering is removed from the DSM-to-DEM transformation, the DEM accuracy improves significantly. In the selected open areas, the SRTM DEM produced an RMSE of less than 1m and the corresponding values for the IFSAR and ADS40 DEMs were between 0.4m and 0.8m. The absolute accuracy for all DEMs was within specifications for all three test sites, though once again the SPOT5 DEM exhibited a large positive elevation bias of greater than 5m.

The three selected forest/bushland sites comprised dense, tall (>10m) eucalypt forest, tall less-dense coastal forest, and scrubland covering a coastal dune with an area of mangroves. It was observed that in the heavily forested areas the accuracy of the SPOT5 DEM was no better than 10m in absolute terms. The ADS40 DEM also showed a high bias value in thick forest, though this was anticipated given the low level of filtering undertaken with this data. Contrasting to the poor accuracy of the SPOT5 and ADS40 DEMs is the result for the airborne IFSAR DEM in the same area, where agreement with the LIDAR DEM is 0.5m RMS. Overall, the results for the forested areas were consistent with expectations, namely that the RMSE is higher than specifications for the DEM technologies would suggest, with the achievable accuracy being inversely proportional to vegetation density.

6. CONCLUSIONS

In most respects, the findings from the evaluation of the performance of DEM generation technologies are consistent with expectations regarding both accuracy and recognised attributes and limitations of the different DEM data sources considered. However, this project has also revealed DEM characteristics that are perhaps not as widely recognized, but are nevertheless important in the context of producing accurate bare-earth DEMs of coastal terrain vulnerable to the impacts of climate change.

The accuracy gap between LIDAR DEMs and those from airborne IFSAR and ADS40 aerial photography at 50cm GSD might only be a factor of three to four according to specifications, eg 15cm elevation accuracy for LIDAR versus 0.5-1m for IFSAR and the ADS40. However, this difference is accentuated by shortcomings in the automated classification and filtering of both vegetation and, to a lesser extent, man-made structures within the DSM-to-DEM conversion. Multiple-return LIDAR displays significant advantages by way of last-pulse ground definition, which cannot be matched in densely vegetated areas by radar and photogrammetry techniques, except through skill-intensive and expensive manual editing processes.

The results obtained for DEM performance in open areas, largely free of trees and buildings, highlight the fact that distinctions in DEM accuracy are as much due to different terrain and land cover, and consequently to filtering, as to differences in basic metric resolution of the different technologies. In the case of the open pasture, sub-metre RMSE values were obtained for the SRTM and Topo DEMs, and the IFSAR and ADS40 DEMs showed sub-half metre RMSE values.

The residual systematic elevation errors attributable to incomplete filtering of DEMs have the potential to compromise the integrity of bare-earth elevation models in low-lying coastal areas that are either heavily vegetated or urbanized. Such land cover accounts for the majority of the populated coastal regions of Australia. As a consequence of the classification/filtering issues, and to a lesser extent, the difference in vertical resolution between different DEM data sources, it can be concluded that LIDAR is the preferred option for DEM generation in coastal regions vulnerable to sea level rise.

REFERENCES

[1] Passini R., Jacobsen K.: Accuracy Analysis of SRTM Height Models, *ASPRS 2007 Annual Conference,* Tampa, USA, 2007 (on CD)

[2] Reinartz P., Müller R., Hoja D., Lehner M., Schroeder M.: Comparison and Fusion of DEM derived from SPOT-5 HRS and SRTM Data and Estimation of Forest Heights, *EARSeL 3D Remote Sensing Workshop*, Porto, Portugal, 2005 (on CD + http://www.earsel.org)

[3] Kornus W., Alamús R., Ruiz A., Talaya J.: Assessment of DEM Accuracy Derived from SPOT-5 High Resolution Stereoscopic Imagery, *Intern. Arch. Photogrammetry, Remote Sens. & Spatial Inform. Sciences*, Vol. XXXV, Part A, Istanbul, 2004, pp. 7-14.

[4] Mercer B.: DEMs Created from Airborne IFSAR – An Update, *Intern. Arch. Photogrammetry, Remote Sens. & Spatial Inform. Sciences*, Vol. XXXV, Part B2, Istanbul, 2004.

[5] Ahokas E., Kaartinen H., Hyyppä J.: A quality assessment of airborne laser scanner data, *Intern. Arch. Photogrammetry, Remote Sens. & Spatial Inform. Sciences*, Vol. XXXIV, Part 3/W13, Dresden, 2003.(on CD)

[6] Fraser, C.S., Ravanbakhsh, M.: Performance of DEM Generation Technologies in Coastal Environments, *CRCSI Report*, 2011, 40 pages.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

PROTOTYPING THE VISUALIZATION OF GEOGRAPHIC AND SENSOR DATA FOR AGRICULTURE

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ABSTRACT

The effectiveness of decision making in agriculture domain can be improved by integrating current local environmental and agro monitoring with Geographic Information System (GIS) and wireless sensor networks (WSN). The presented paper describes conceptual approaches to cartographic visualization methods of agricultural and metrological data acquired by WSN and portal prototype for integrated visualization. Each sensor used for agricultural applications has a location and can be placed within a broader spatial extent. Soil quality, air pressure, and crop sensor characteristics in a specific region can be automatically monitored at frequent intervals and those readings can be aggregated with geospatial data from diverse sources into map representation (geovisualization) for diverse purposes. Interoperable web services and data encoding models for Spatial Data Infrastructures (SDI) further foster the integration of sensor networks data with existing geospatial infrastructures. Experimental portal for sensor data and geospatial data integration and visualisation was designed and prototyped based on open source interoperable platform. The introductory phase of sensors and cartographic outputs integration includes the development of base maps (general overview map, basic topographic information, WMS data from various public sources), thematic maps (soil conditions, crops variability), and sensor maps (spatio-temporal variability of project WSN). The portal, besides the above mentioned cartographic functionality, also complies with basic interoperability rules for a seamless integration of available geospatial resources in the form of OGC web map services.

1. INTRODUCTION

The Digital Earth concept seeks ways of providing access to spatially referenced information and knowledge resources to everyone. In order to achieve that goal, many problems have to be addressed ranging from political and financial matters to technological solutions. One of the key issues is the development of methods for selection of data matching user's requirements and its suitable presentation in way which allows users its quick and correct understanding. The presented paper deals with methods of acquisition, processing and visualization of sensor data for agricultural applications.

2. WIRELESS SENSORS AND AGRICULTURE

2.1. Wireless Sensor Network and Sensor Web concept

The dynamics of plant growth is depending on the dynamics of environmental data such as soil (or air) temperature and humidity and solar radiation which can be measured using stationery local weather stations or wireless sensor networks (WSN). WSN are a new technology that can provide processed real-time field data from sensors physically distributed in the field (Camilli et al. 2007). Akyildiz et al. (2002) described WSN as networks of small sensor nodes with limited processing capacity, including sensors and their specific conditioning circuitry, that communicate over short distances, normally using radio frequencies.

Separated sensor networks are currently being integrated into a new internet based concept – the so-called Sensor Web. Zyl et al. (2009) described this concept as an infrastructure that supports the vision of an integrated system of sensor systems or individual sensors, providing access to sensors, sensor networks, and corresponding observational datasets. The Sensor Web integrates heterogeneous sensors, both in-situ and remote sensing devices, as well as stationary sensors or those attached to mobile platforms. From a purely systematic point of view we can imagine the Sensor Web as an open complex adaptive system, organised as a network of open access sensor resources (including both data and metadata), which pervades the Internet and provides external access to sensor resources.

2.2. Sensor Web applications in agriculture

Wang et al. (2006) presented an overview on recent development of wireless sensor technologies and classified the applications in agriculture and food production into several categories naming environmental monitoring (weather monitoring, geo referenced environmental monitoring) and precision agriculture (spatial data collection, precision irrigation) as the most spatially dependant.

Environmental data are very important in agriculture, since crop yields depend on environmental conditions, and the response of plant growth to changing environmental conditions is extremely complicated (Lee et al. 2010). The measurements of agronomical phenomena are mainly required for modern agricultural practices called precision agriculture. The aim of precision agriculture is optimization of production inputs (fertilizers, pesticides, fuel, etc.) based on local crop requirements and plant requirements. This approach to crop management can lead to the effective use of agrochemicals and avoidance of environmental risks.

The aspects of precision agriculture are described by Pierce and Elliott (1999). They defined precision agriculture as “the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality”. Assessing variability is the critical first step since one cannot manage what one does not know. The factors and properties that regulate crop growth and yield vary in space and time. The higher the spatial variability of soil conditions (or crop properties), the higher the potential for precision management and the greater its potential value. The degree of difficulty, however, increases with higher dynamics of temporal component.

2.3. Integration of sensors and geospatial infrastructure

Since 2002, the Open Geospatial Consortium (OGC) has managed an initiative called Sensor Web Enablement (SWE) for building a framework of open standards for exploiting web-connected sensors and sensor systems of all types. The initial focus of OGC's SWE has been to investigate standardized interfaces for live sensors operating in near-real-time, rather than the conventional static data stores. It addresses information gathering from distributed, heterogeneous, dynamic information sensors and sources of different structure, based on web services.

Since 2007, OGC members have been working on the second version of SWE. Bröring et al. (2011) describes that SWE 2.0 brings higher coherency of individual SWE specifications together with conceptual and formal clarity rather than new features. At the moment, the SWE Common Data Model Encoding, Observations and Measurements, and Sensor Planning Service specifications are available in the version 2.0; other SWE specifications are expected to be published during 2011. The most expected specifications are SensorML 2.0 and SOS 2.0, because the first one specifies XML encoding of SWE and the second one provides specification of access to measured sensor values. Observations and Measurement 2.0 is the first part of the SWE standards family to become an ISO standard (ISO 19156).

3. VISUALIZATION OF SENSOR DATA

Visualization is important when working with sensor data. When properly selected, it makes it more comfortable for a user to work with the data and the data can be understood more quickly and easily. With suitable visualization, it is possible to find patterns, connections or similarities in numerical data. That makes it much more convenient than manual analysis of raw sensor data, which is sometimes impossible to understand for a person. Sensor taxonomy or classification for the field of applications where sensors are used (see White 1987, Richter 2009, Zerger et al. 2010 for examples) can help a developer when implementing a visualization.

3.1. Conceptual background

Sensor data usually exists in numerical values; therefore, the process of understanding or analysing it is not trivial. In many cases finding patterns, differences, and commonalities is hardly possible. Visualizations take the numerical data, analyse it, use extraction and aggregation methods and then give the user a graphical interface and representation of the input data. This representation makes it easier to understand the data and to interact in the data set (Richter 2009). According to Plaisant (2004), the biggest problem when designing visualizations is the fitting of visualization to the wishes of the user, to the task and to real world problems. Trying to display the data, different views of the same data set should be available. These features have to be implemented and the properties of sensor data have to be regarded to have a good visualization of sensor data. There is a dependency between the task and the visualization, so the task of the sensor is one starting point.

Another starting point can be found in the topic of information visualization. Several authors (Andrienko and Andrienko 2006, Richter 2009) are quoting Shneiderman (1996) and his "Visual Information Seeking Mantra" as a starting point to create a good visualization. Shneiderman proposed type by task taxonomy (TTT), where individual types are conceptually represented by seven data types (1-, 2-, 3-dimensional data, temporal and multi-dimensional data, and tree and network data) with associated attributes. These basic data types are searchable and selectable by attribute. On the other hand, he enumerated the following seven tasks at a high level of abstraction when creating a design:

- Overview – gain an overview of the entire collection.
- Zoom – zoom in on items of interest.
- Filter – filter out uninteresting items.
- Details-on-demand – select an item or group and get details when needed.
- Relate – view relationships among items.
- History – keep a history of actions to support undo, replay and progressive refinement.
- Extract – allow extraction of sub-collections and of the query parameters.

Andrienko and Andrienko (2006) further developed the basic four principles (overview, zoom and filter, and details on demand) for exploratory data analysis, slightly changing principles naming for “see the whole”, “zoom and focus”, and “attend to particulars”. The main principle is to give an overview of the whole data set. To take a closer look at special data, there are tools that allow zooming functions or which filter away uninteresting data.

4. AGRISENSOR – FROM CONCEPT TO PILOT STUDY

The Agrisensor project (Kubicek et al. 2009) follows the above mentioned concepts and aims to design and develop an integrated framework of cartographic visualisation for agricultural applications based on wireless sensor networks information.

4.1. Monitoring methods

In the Agrisensor research project, the agricultural monitoring of key weather and soil parameters using sensors is realized in three complementary levels with different spatial extent and temporal intensity:

A. Mapping of spatial variability of soil and field crops in large fields. Verification was carried out at two different localities in South Moravia region (Czech Republic): Field “Pachty” (52.5 ha) with chernozem soil type and sandy clay loam texture, and Field “Haj” (37.8 ha;) with haplic luvisol and silt loam texture. The measurement is done several times in a year by ground based survey (soil moisture, temperature, soil compaction), on-the-go methods (electrical conductivity) and remote sensing (aerial multispectral, hyperspectral and thermal imaging).
B. Monitoring of temporal dynamics of weather parameters, which are important for crop growth (soil and air temperature, soil moisture, air humidity) is done by sensor nodes. Low count (5) of sensor nodes is distributed at mentioned localities over each field to cover areas with contrasting soil condition. Other important meteorological parameters as precipitation, solar radiation, and wind speed and air flow direction are measured by meteorological station installed at a farm located 3 km from the experimental fields. Their changes over field area are considered as constant. Combination of both surveys can model the spatio-temporal changes of observed meteorological characteristics for selected field and crop and can implement it into decision support systems used in site specific crop management.
C. Monitoring of dynamics of key agro-meteorological parameters in different crops species (maize, winter wheat, spring barley, potatoes) and soil tillage practices (traditional,

conservation). The measurements are carried out by sensor nodes under controlled conditions in small-plot experiments at the Field Experiment Station of Mendel University in Brno. The obtained results will provide information about the differences in the parameters among individual crops and variants of their crop management practices.


Figure 1: Sensor node installed in maize small-plot field at Field Experiment Station of Mendel University in Brno (left) and meteorological station installed at the farm near to "Haj" field (right).

4.2. Data flow and maintenance

Experimental wireless sensor network is composed from two hierarchical hardware components:

- L1 – series of peripheral wireless sensors communicating with RFID protocol. Each sensor node includes a master processor and digital input/output with units measuring temperature and humidity for both soil and air. Besides meteorological variables also technological information are measured (signal strength, battery voltage) for better network maintenance.
- L2 – mobile communication unit based on ARM processor and GPRS communication unit. This unit has a twofold function within the WSN – it is equipped with independent meteorological sensors (for data calibration) and also includes radio module for communication with L1 level nodes. L2 node is responsible for data pre-processing.

Each sensor of L1 component measures its phenomenon in preconfigured time period which is typically several seconds or minutes. When new value is measured, it is instantly transferred using local wireless network to the L2 component. From the L2 component the value is automatically sent to the remote main server using GPRS (General Packet Radio Service) connection. Main server then performs insertions of data to the database.

When the measured data is stored in the central database, it is accessible to the user by another Java web service which is based on Sensor Observation Service (SOS) specification. At the moment, the service is not fully SOS 1.0 compliant; however, it follows all major concepts and supports request describing units, i.e. set of sensors within the same location, request describing sensors and observed phenomena, and request for obtaining measure values. Java web service brings the measured data from database to the client side in JSON format (JavaScript Object Notation). This format can be then easily used for AJAX (Asynchronous JavaScript and XML) based client application and near real time updating of visualization.

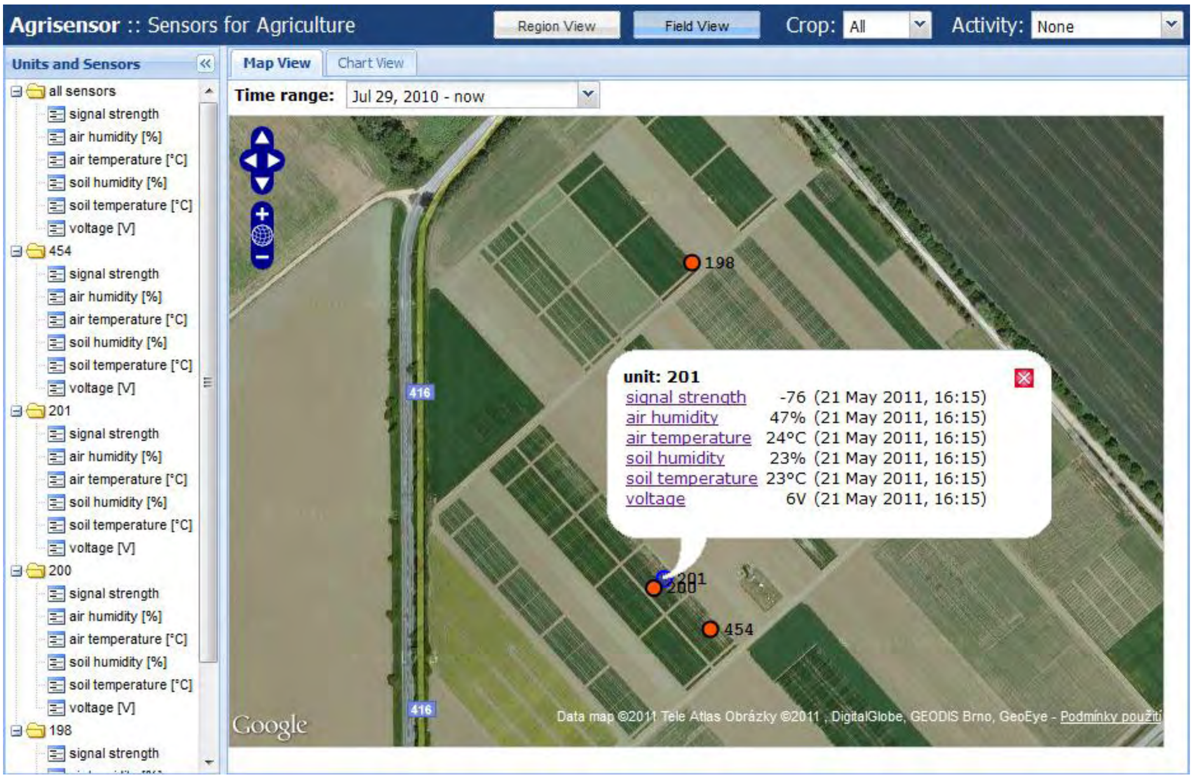

Figure 2: Map view within the client

4.3. Preliminary results

For exploring and visualization of measured sensor data, an interactive web client was developed implementing basic conceptual principles described above. Namely the multiple view and tasks (overview, zoom and filter, and details on demand) principles were followed. The client has two main views: map view and chart view (fig. 2 and 3). The map enables hierarchical predefined views from a general overview of the entire studied area, through the particular agricultural experimental plots to the detail view of sensors location. In the most detailed view, units (i.e. poles with set of sensors) are displayed. By clicking on unit symbol, new window with latest measured values appears. In the chart view, an interactive chart is drawn based on user specified sensor and time range. It is also possible to choose all sensors measuring the same phenomenon so that the difference between measurement places can be seen. Below the chart, user can see statistical information about currently displayed dataset. Finally, the user is able to export or print the chart.

Catalogue of available geospatial data both from local and remote Web Map Services (WMS) was developed for selected experimental fields. This set of geodata sources is intended for the general overview and global views of experimental plots. It also serves as a knowledge base for visual exploration of spatio-temporal dependencies between measured sensor data and environment. Local geographic data were measured and collected for the most detailed level dealing with individual sensors location including the history of particular crops location and their alternative cultivation.

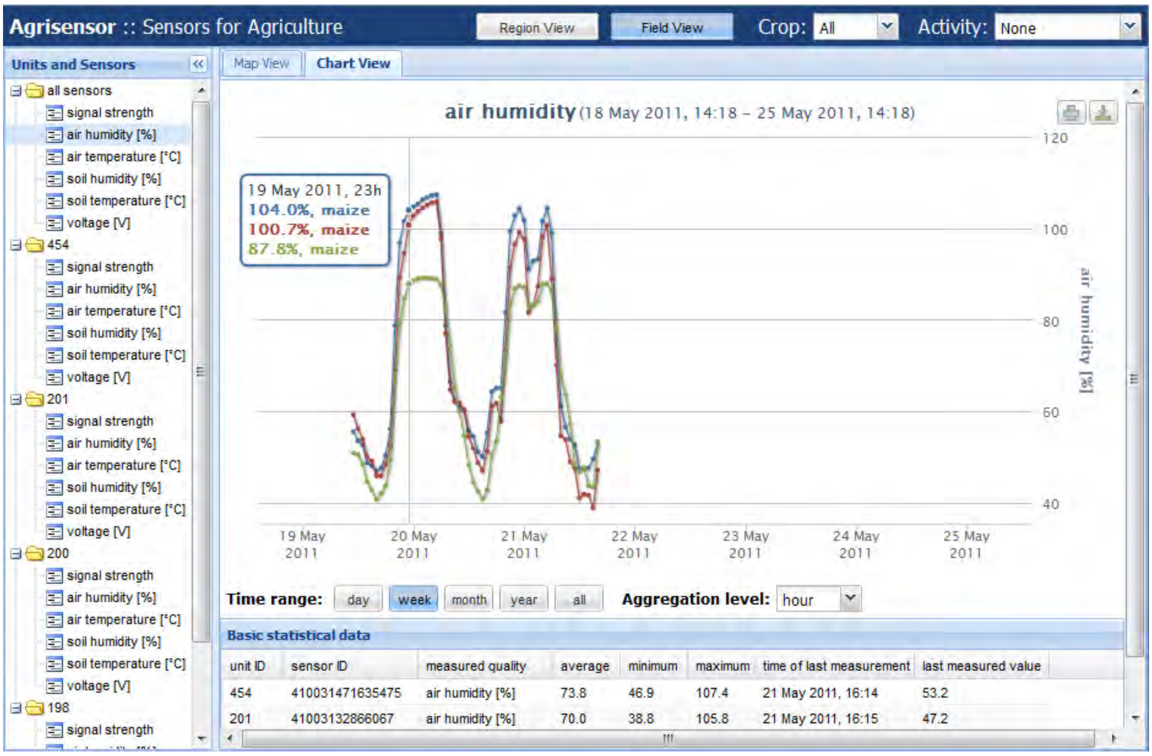

Figure 3: Chart view within the client

Second part of preliminary results deals with acquisition of local information about the agronomic spatial variability of experimental plots. At both experimental localities, ground based mapping and remote sensing of within-field spatial variability of soil using different methods was carried out. Information about soil conditions to the depth of 0.75 m were obtained by on-the-go measurement of soil electrical conductivity, which enables rapid and non-invasive identifications in soil substrate. Methodology and results of this survey were described by Lukas et al. (2009).

5. CONCLUSION AND FUTURE DIRECTIONS

Wireless sensors networks geovisualization is presented in the paper on two different levels of abstraction – the higher level deals with the conceptual approach and presents the theoretical background of wireless sensor networks in agriculture and sensor geovisualization issues. The lower level is focused on application stage and describes selected problems prototyped within the framework of Agrisensor project.

Further development of visualization client is planned. The main focus is on the so-called context aware or adaptive visualization (Kubicek and Kozel 2010, Kozel and Stampach 2010). A context influences map compositions and chart appearance for specific agriculture situations (e.g. maize harvesting or wheat sowing).

The Agrisensor project is supported by the grant no. 205/09/1437 of the Czech Science Foundation.

REFERENCES

[1] Camilli A., Cugnasca C. E., Saraiva A. M., Hirakawa A. R., Corrêa P. L. P.: From wireless sensors to field mapping: Anatomy of an application for precision agriculture. *Computers and Electronics in Agriculture*. 58 1), pp. 25-36. 2007.

[2] Akyildiz I. F., Su W., Sankarasubramaniam Y., Cayirci E.: Wireless sensor networks: A survey. *Computer Networks*. 38 4), pp. 393-422. 2002.

[3] Zyl T. L. van, Simonis I., McFerren G.: The Sensor Web: systems of sensor systems. *International Journal of Digital Earth*. Vol. 2(1), pp.16-30. 2009.

[4] Wang N., Zhang N., Wang M.: Wireless sensor in agriculture and food industry – Recent development and future perspectives. *Computers and Electronics in Agriculture*, 50 1), pp.1-14. 2006.

[5] Lee W. S., Alchanatis V., Yang C., Hirafuji M., Moshou D., Li, C.: Sensing technologies for precision specialty crop production. *Computers and Electronics in Agriculture*. 74 1), pp. 2-33. 2010.

[6] Pierce F. J., Elliott T. V.: Regional and on-farm wireless sensor networks for agricultural systems in Eastern Washington. *Computers and Electronics in Agriculture*. 61 1), pp. 32-43. 2008.

[7] Bröring A., Echterhoff J., Jirka S., Simonis I., Everding T., Stasch Ch., Liang S., Lemmens R.: New Generation Sensor Web Enablement. *Sensors*, 2011 11), pp. 2652-2699. 2011.

[8] White R.: A Sensor Classification Scheme. *Ultrasonic, Ferroelectrics and Frequency Control, IEEE Transactions on*, 34 2), pp. 124-126. 1987.

[9] Richter R.: Visualizing sensor data. Media Informatics Advanced Seminar on Information Visualization. 2009.

[10] Zerger A., Viscarra Rossel R. A., Swain D. L., Wark T., Handcock R. N., Doerr V. A. J., Bishop-Hurley G. J., Doerr, E. D., Gibbons P. G., Lobsey C.: Environmental sensor networks for vegetation, animal and soil sciences. *International Journal of Applied Earth Observation and Geoinformation*. 12 5), pp. 303-316. 2010.

[11] Plaisant C.: The challenge of information visualization evaluation. *Proceedings of the working conference on Advanced visual interfaces*, pp. 109–116. ACM New York, NY, USA. 2004.

[12] Andrienko N., Andrienko G.: Exploratory Analysis of Spatial and Temporal Data. Springer – Verlag, Berlin Heidelberg, 703 p. 2006.

[13] Shneiderman B.: The eyes have it: a task by data type taxonomy for information visualizations. *Proceedings IEEE Symposium on Visual Languages*, pp. 336-343. 1996.

[14] Kubicek P., Charvat K., Lukas V.: Cartographic visualization of agricultural sensor. *Sborník ze společné mezinárodní konference ISZL/CEE-SDI/ ICT for Rural 2009*. Praha : Česká zemědělská univerzita, 9 p. ISBN 978-80-213-1932-5. 2009.

[15] Lukas V., Neudert L., Kren J.: Mapping of soil conditions in precision agriculture. *Acta Agrophysica* 13(2), pp. 393-405. 2009.

[16] Kubicek P., Kozel J.: Cartographic techniques for adaptive emergency mapping. In Kremers, H., Susini, A. eds. Risk Models and Applications. Lecture Notes in Information Science Berlin : CODATA-Germany, pp. 49-62. 2010.

[17] Kozel J., Stampach R.: Practical Experience with a Contextual Map Service. In Geographic Information and Cartography for Risk and Crisis Management - Towards Better Solutions. 1st Edition. Heidelberg Dordrecht London New York : Springer -Verlag, 2010. Lecture Notes in Geoinformation and Cartography, pp. 305-316. ISBN 978-3-642-03441-1. 2010.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

COMBINED ANALYSIS OF OPTICAL AND SAR REMOTE SENSING DATA FOR FOREST MAPPING AND MONITORING

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ABSTRACT

Jointly processing remote sensing (RS) data acquired by sensors operating at different wavelengths offers the potential to significantly improve the operation of global forest mapping and monitoring systems. This paper presents an analysis of the forest discrimination properties of optical imagery (Landsat TM) and synthetic aperture radar (SAR) data acquired at L-band (ALOS-PALSAR) and C-band (RADARSAT-2), when considered either separately or as a combined source of information. This pilot study is carried out over a test site in north-eastern Tasmania, Australia. Canonical variate analysis, a directed discriminant technique, is used to investigate the separability of a number of training sites, which are subsequently used to define spectral classes for maximum likelihood classification. An accuracy assessment of the forest classification results is provided on the basis of independent validation data. A variable selection is also performed, producing quantitative metrics on the degree of land cover separation provided by various combinations of the SAR and optical bands. The experimental results highlight the advantages of combining multi-sensor RS data for purposes such as natural resources and land management, environmental assessment, and carbon accounting.

1. INTRODUCTION

The use of RS data provides an important source of information for environmental monitoring, as demonstrated in many application fields ranging from conservation and natural resources management [1] to carbon accounting [2]. Recent technological advances have also allowed the deployment of many new RS satellites, particularly in the field of SAR. In parallel, the development of robust methods for large-scale forest monitoring is also becoming increasingly important. The joint analysis of multi-sensor data can potentially improve the operation of environmental monitoring systems significantly.

The need for global forest monitoring systems is demonstrated by the recent launch of several multi-governmental initiatives such as the Forest Carbon Tracking task of the Group on Earth Observations (GEO-FCT, www.geo-fct.org). In response to GEO-FCT, the Australian Department of Climate Change and Energy Efficiency (DCCEE) launched the International Forest Carbon Initiative (IFCI), which aims to increase international forest carbon monitoring and accounting capacity in accordance with emerging international reporting and verification requirements. Land cover monitoring systems based on optical RS data have been operational for many years in several parts of the world. In Australia, the National Carbon Accounting System (NCAS [2], [3]) offers the capability for fine-scale continental mapping and monitoring of the extent and change in perennial vegetation using Landsat satellite imagery, allowing for an effective estimation of the greenhouse gas emissions from land use and land use changes [4]. Among others, future developments of the NCAS framework under IFCI involve taking advantage of new technologies in the area of spaceborne SAR sensors.

An important step towards multi-sensor environmental monitoring is to address the key aspect of sensor complementarity (adding thematic value by using more than one sensor), and thus to quantify the performance gains achievable by using a SAR–optical data fusion approach. This article demonstrates the potential use of combined optical and SAR data for the purpose of forest monitoring, and presents a quantitative analysis and comparison of the forest/non-forest (F/NF) discrimination results. It reports some of the findings obtained from the work carried out in the frame of Australia's contribution to the GEO-FCT initiative.

2. DATA AND STUDY AREA

2.1. Study Area

This work is part of a pilot study carried out for a 66km×50km demonstration area in north-eastern Tasmania, Australia (Figure 1, left), which includes one of Australia's national calibration sites defined in the frame of the GEO-FCT initiative. It contains a variety of land covers including rainforests, wet and dry eucalypt forests, non-eucalypt forests, pine and eucalypt plantations, agricultural land, as well as treeless alpine and moorland vegetation. Significant topographic variations can also be found across the study site with the terrain elevation varying between 85m and 1510m above sea level.

2.2. ALOS-PALSAR Data

The ALOS-PALSAR data in this study were acquired at L-band (~23.6cm wavelength) in fine-beam dual-polarisation mode (HH and HV), in an ascending orbit with off-nadir angle of 34.3°. In the study area, the data is a mosaic of two PALSAR scenes, namely scene 381/6340 in the west (acquired on 07 Oct. 2009) and scene 380/6340 in the east (acquired on 20 Sept. 2009). The single-look complex data (SLC level 1.1) was pre-processed according to the following steps: 1.) 8×2 multi-looking (range × azimuth) resulting in a 29.8m×25.1m pixel size, 2.) speckle filtering with 5×5 Lee filter, 3.) radiometric calibration and normalisation, 4.) geocoding to 25m pixel size to match the Landsat resolution, using a digital elevation model (DEM) with 25m cell resolution, 5.) terrain illumination correction using the 25m DEM, and 6.) gradient mosaicing of the two scenes. The result is a mosaic of orthorectified, terrain-corrected and radiometrically calibrated PALSAR data at 25m resolution (Figure 1, centre-left). The terrain correction step is necessary to compensate for illumination differences due to the topographical variations and side-looking orientation of the SAR sensor. This correction was carried out using the algorithm described in [5], which considers the SAR scattering in forested areas together with the local slope angles to derive the terrain correction coefficients.

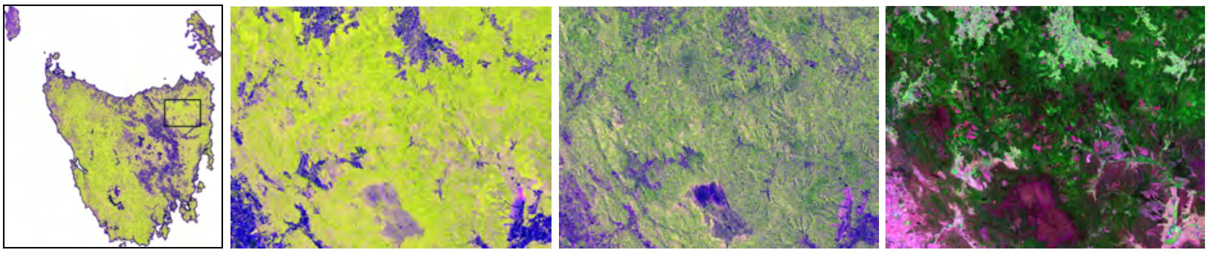

Figure 1: SAR and optical datasets. *Left to right:* PALSAR mosaic over Tasmania (the box shows the 66km×50km area of interest); PALSAR data ($\sigma°$ in dB) for the study area, HH/HV/HH-HV in R/G/B; RADARSAT-2 data ($\sigma°$ in dB), VV/VH/VV-VH in R/G/B; and Landsat-TM data , bands 5/4/2 in R/G/B.

2.3. RADARSAT-2 Data

The C-band data (~5.6cm wavelength) used here was acquired by the RADARSAT-2 sensor in wide-beam (W3) dual-polarisation mode (VV and VH) with an incidence angle of 42.2° in ascending orbit. The data covering the study area is part of a scene acquired on 07 Sept. 2009. Data pre-processing was carried out in a manner similar to that used for the PALSAR data (see Section 2.2). Here, the multi-looking step used 1 range look and 4 azimuth looks (resulting ground pixel size: 17.6m×25.7m), and no mosaicing was necessary. The resulting C-band data is shown in Figure 1 (centre-right).

2.4. Landsat-TM Data

Optical data was obtained from the existing archive of calibrated Landsat MSS/TM/ETM+ images produced as part of Australia's NCAS program [2]. Within this framework, each Landsat scene was processed according to the following steps: 1.) orthorectification to a common spatial reference, 2.) top-of-atmosphere reflectance calibration (sun angle and distance correction), 3.) correction of scene-to-scene differences using bi-directional reflectance distribution functions, 4.) calibration to a common spectral reference using invariant targets, 5.) terrain illumination correction, 6.) removal of corrupted data (e.g. regions affected by smoke, clouds and sensor deficiencies), and 7.) mosaicing of individual Landsat scenes into 1:1,000,000 map sheets. Key aspects of this processing are discussed in [2] and full operational details are given in [3]. The data covering the study area was acquired on 17 Jan. 2009 (scene 090/88), with data from Feb. 2009, Mar. 2009 and Feb. 2010 used as fill-in in cloud-affected areas (~18% of the image). The resulting Landsat mosaic is shown in Figure 1 (right).

2.5. Data Coregistration

Ideally, accurate coregistration between the optical and SAR images would be established with the use of cross-correlation techniques, image to image registration, and a common DEM in order to achieve sub-pixel alignment. Here, a common DEM was used but the SAR data was orthorectified using the sensors' orbital parameters while the Landsat data was taken from the legacy NCAS system, which used historic state topographic mapping as primary control. The coregistration between datasets was therefore assessed with the use of a gradient cross-correlation technique [6], which provides sub-pixel assessment results by detecting and matching features in the two images being compared.

The PALSAR–Landsat coregistration was assessed using 127 ground features, leading to an accuracy of 0.56 pixel (25m pixel size) with 96% of the residuals below 1.5 pixels, and with no apparent signs of systematic spatial deviations between the two images. The RADARSAT-2 data was originally found to be poorly coregistered with the Landsat image (south-east shift of about 2.4 pixels); the RADARSAT-2 image was thus re-registered to the optical data. The increased speckle in the RADARSAT-2 image produced more variability in the coregistration results, here only allowing 90 ground features to be used for the assessment. The average displacement of the re-registered RADARSAT-2 data compared to Landsat was found to be 1.05 pixels with about 74% of the residuals below 1.5 pixels. Based on these results, the datasets' coregistration was considered satisfactory for joint SAR–optical processing.

2.6. Reference Data

Selection of the training and validation sites for the following analyses was based on a consideration of SPOT imagery (2.5m resolution) and a vegetation map product (TASVEG) from the state of Tasmania. In the area of interest, the SPOT image was a mosaic of four scenes acquired between Nov. 2009 and Feb. 2010. The TASVEG map was used to obtain land cover information, and the SPOT data provided an added check on whether the cover had deviated or changed from the TASVEG label. TASVEG is a Tasmania-wide vegetation map produced by the Tasmanian Vegetation Mapping and Monitoring Program within the Department of Primary Industries and Water (www.thelist.tas.gov.au). It comprises 154 distinct vegetation communities mapped at a scale of 1:25,000, and provides a reference that can be used for a broad range of management and reporting applications relating to vegetation in Tasmania. This information is based on a combination of field observations, photo-interpretation and information from other sources such as geological maps and permanent inventory plots. TASVEG is continually revised and updated to reflect changes in the natural environment. In the study area, field work for revision mapping started in Mar. 2005 and was completed in Oct. 2008. The selection of training and validation data was also done in conjunction with the optical and SAR imagery so as to minimise potential errors due to the different acquisition times of the reference data.

3. FOREST/NON-FOREST CLASSIFICATION

The F/NF discrimination analyses were applied to the following datasets: 1.) Landsat (six spectral bands, thermal band omitted), 2.) PALSAR (L-band, HH and HV), 3.) RADARSAT-2 (C-band, VV and VH), and 4.) combined SAR–optical data obtained by concatenating the Landsat, PALSAR and RADARSAT-2 bands (ten spectral bands). Using the reference data, 268 training sites (each approximately 150 to 200 pixels in size) were selected for the classifications so as to represent a broad range of land covers over the study area. The same training sites were used for all datasets, but aggregated separately in each analysis.

3.1. Definition of Spectral Classes

Using the training data, canonical variate analysis (CVA) produces a set of orthogonal linear basis functions (canonical vectors, CVs) based on maximising the ratio of between-class separation to within-class variance [7]. The metrics and plots produced by this technique provide information on whether to group or not to group certain sites. The analysis also indicates how reliably the selected sub-classes may be separated. For each of the SAR and optical datasets, CVA was used to aggregate the training sites into a number of sub-classes to reflect the common spectral characteristics of different land covers. Figure 2 shows the CVA plot obtained for the Landsat data, with the sites displayed in the space defined by the first two CVs. This figure also shows four sub-classes selected for this data, with labels identifying the land cover types represented by these groupings.

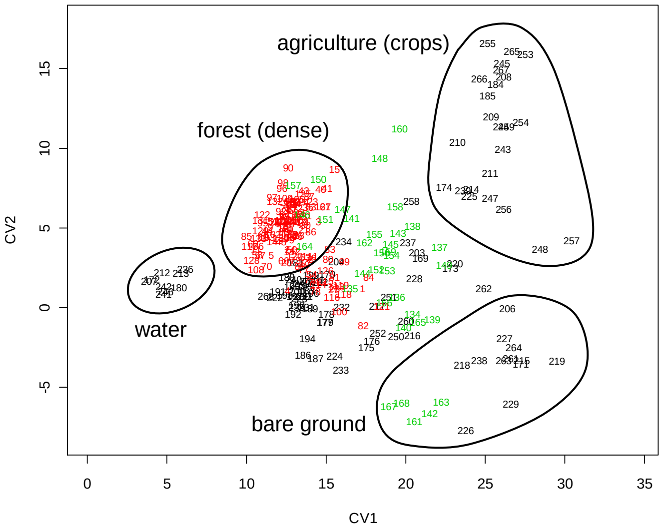

Figure 2: CVA plot for the Landsat data, showing four of the selected seven sub-classes (three more classes selected among the remaining sites).

The number of selected sub-classes reflects the ability of each dataset to discriminate between different land covers. A total of seven sub-classes could be identified for Landsat, six for PALSAR, four for RADARSAT-2, and eight for the combined SAR–optical dataset. Table 1 shows a list of these sub-classes, providing information as to which land cover types are separable based on each data. It must be noted that sites from the ‘immature plantations’ sub-class were here assigned to the non-forest category, due to their “bare ground” appearance in the Landsat and SPOT imagery; plantation sites were defined as mature when presenting a closed/dense canopy. Also, some separation appeared possible between native forests and certain ‘mature plantations’ sites in the SAR and optical data. This was however not investigated further due to a lack of accurate ground information regarding plantation types (hardwood vs. softwood) and age of the forestry stands in the study area.

	Landsat TM	PALSAR L-band	RADARSAT-2 C-band	Combined SAR–optical
Forest	1. dense forest (native and plantations) 2. sparse forest	1. dense forest (native and plantations) 2. mix of dense and sparse forest	1. (*) mix of sparse and dense forest (native and plantations), and harvested/immature plantations	1. dense forest (native and plantations) 2. sparse forest
Non-forest	3. water 4. agriculture (crops) 5. mix of agriculture (bare) and immature plantations 6. mix of alpine and Buttongrass vegetation 7. generic bare ground	3. water 4. generic agriculture 5. Buttongrass moorland 6. mix of alpine treeless vegetation and im-mature plantations	2. water 3. Buttongrass moorland 4. generic non-forest (agriculture and alpine treeless vegetation)	3. water 4. agriculture (crops) 5. immature plantations 6. Buttongrass moorland 7. alpine treeless vege-tation 8. generic bare ground

Table 1: definition of sub-classes based on a CV analysis of the training data. (*) Note: the first class for the RADARSAT-2 data corresponds to a mix of forest and non-forest (immature plantations) sites.

3.2. Maximum Likelihood Classification

The spectral groupings identified in the previous section provided the classes used for a contextual maximum likelihood classifier (MLC), which produces a sub-class label image based on the input data

[8]. Maximum likelihood classification was used due to its ability to provide distance metrics related to the separation of the selected sites and sub-classes.

A quantitative assessment of the F/NF classifications was carried out on the basis of 204 validation sites uniformly distributed over the study area and selected independently of the training data. For this assessment, the multi-class MLC outputs were collapsed into forest and non-forest labels according to the definitions given in Table 1. Table 2 presents the resulting classification accuracy and confusion matrices as the percentage of validation sites mapped to the forest and non-forest classes by the MLC.

	Landsat		PALSAR		RADARSAT-2		SAR–optical	
true labels	F	NF	F	NF	F	NF	F	NF
F	60.78%	5.88%	64.22%	2.45%	64.71%	1.96%	61.27%	5.39%
NF	4.41%	28.92%	3.92%	29.41%	13.24%	20.10%	3.92%	29.41%
Accuracy	89.70%		93.63%		84.81%		90.68%	

Table 2: F/NF classification percentages (confusion matrices) of MLC outputs given the true labels.

These results show good classification accuracy (~90%) for the Landsat, PALSAR and combined SAR–optical data, with significantly lower results obtained with the RADARSAT-2 data. The slightly decreased accuracy achieved by the combined SAR–optical data compared to PALSAR is due to the intrinsic variability of the validation results (error margin) rather than major differences between the F/NF classifications, as can be seen in Figure 3. This figure shows the multi-class MLC outputs for a subset of the study area, and clearly demonstrates the superiority of the combined dataset (bottom-right image) in classifying land covers, especially regarding the separation of the Buttongrass moorland (yellow areas in the north-east corner of the plots) from the alpine vegetation (south-west corner).

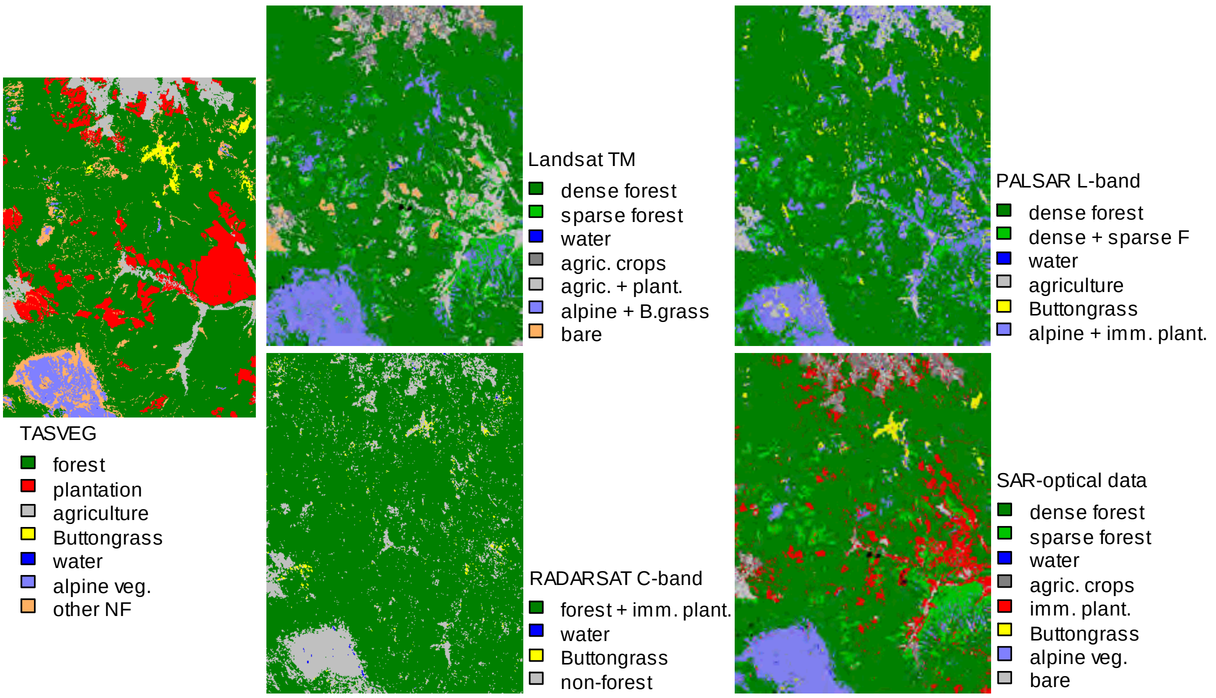

Figure 3: multi-class MLC outputs over a 25km×33km subset of the study area, for the Landsat data (*top-centre*), PALSAR data (*top-right*), RADARSAT-2 data (*bottom-centre*) and combined SAR–optical dataset (*bottom-right*). The image on the left shows the reference data (TASVEG), with plantation areas shown in red regardless of their state (harvested, re-planted or mature).

3.3. Band Information

Another aspect of interest for multi-sensor integration is to examine the level of information provided by different combinations of the optical and SAR bands; this is achieved here by performing a variable selection analysis [9]. Table 3 presents the results as the percentage of discrimination provided by various subsets of bands with respect to the information available when all bands are considered simultaneously. This assessment is furthermore performed for three different scenarios used to check the separation existing between different sub-classes of training data (using the class aggregations defined for the combined SAR–optical dataset, see Table 1, last column).

The column labelled 'Forest vs. non-forest' in Table 3 presents generic discrimination results when all the forest sites are compared (contrasted) to all the non-forest sites (sites from the 'water' sub-class were removed from this analysis due to their clearly-separable spectral signatures). This column indicates that the optical data contains an equivalent of 57.29% of the F/NF discrimination information, while the PALSAR data on its own would provide 66.32% of this information and the RADARSAT-2 data 5.21%. In the case of PALSAR, most of the F/NF information (66.32%) is available from the HV polarisation alone (66.28%), while most of the RADARSAT-2 discrimination (5.21%) is available from the VH band (5.13%). This dependence on the cross-polarised bands is likely due to the influence of volumetric SAR scattering in forested areas. Finally, this example also shows that considering all the available data jointly leads to a significantly increased ability to separate the forest and non-forest sites (with an increase of at least 33% compared to using the optical or SAR data alone), thus demonstrating the complementary nature of the information provided by the SAR and optical sensors.

Bands	Forest vs. non-forest	Contrast 1	Contrast 2
PALSAR HH	17.33%	10.68%	5.95%
PALSAR HV	66.28%	30.29%	15.97%
PALSAR HH+HV	66.32%	30.76%	16.24%
RADARSAT-2 VV	0.25%	6.35%	0.41%
RADARSAT-2 VH	5.13%	24.95%	0.27%
RADARSAT-2 VV+VH	5.21%	25.69%	0.41%
TM (6 bands)	57.29%	40.88%	93.37%
TM+SAR (10 bands)	100.00%	100.00%	100.00%

Table 3: percentage of the discrimination information provided by different combinations of the optical and SAR bands (compared to using all available bands).

The last two columns in Table 3 contain results related to the discrimination between the least separable forest class ('sparse forest' in Table 1) and the two spectrally closest clusters of non-forest sites. The column labelled 'Contrast 1' corresponds to a contrast between 'sparse forest' and 'alpine vegetation', with the results leading to conclusions similar to those discussed above for the 'Forest vs. non-forest' contrast. The column 'Contrast 2' results from contrasting 'sparse forest' against the 'immature plantations' class. In this particular case, most of the discrimination is provided by the optical data, thus indicating a relative inability to separate these ground covers using the SAR data alone. This is likely the result of forestry logging and planting practices in this region of Tasmania, where debris (branches, logs, etc.) are often left on the ground following the harvesting of a plantation and subsequent planting of new seedlings (thus generating a strong cross-polarised backscatter). This observation is also in keeping with the class definitions shown in Table 1, where 'immature plantations' sites are always part of a mixture with other types of land cover for the PALSAR and RADARSAT-2 data (similar spectral signatures).

4. CONCLUSION

This paper investigated the forest discrimination properties of combined SAR and optical data. Significant classification improvements resulted from the combined data in comparison to using Landsat, L-band SAR (PALSAR) or C-band SAR (RADARSAT-2) independently. A variable selection analysis also showed a varying degree of discrimination provided by each of the SAR and optical bands, depending on the considered land cover types. The results also generally point to a significantly increased forest mapping capacity of the L-band SAR data compared to C-band. All the results presented in this work highlight the complementary nature of SAR and optical sensors for the purpose of forest mapping and monitoring. This paper also demonstrated how existing statistical methods (such as canonical variate analysis, variable selection and maximum likelihood classification) can be used as efficient investigation/classification tools so as to take full advantage of these complementary datasets.

REFERENCES

[1] J. Wallace, G. Behn, and S. Furby, “Vegetation condition assessment and monitoring from sequences of satellite imagery,” *Ecological Management and Restoration*, vol. 7, no. 1, pp. 31–36, Jun. 2006.

[2] P. Caccetta, R. Waterworth, S. Furby, and G. Richards, “Monitoring Australian continental land cover changes using Landsat imagery as a component of assessing the role of vegetation dynamics on terrestrial carbon cycling,” in *European Space Agency Living Planet Symposium*, pp. 1–7, Bergen, Norway, June-July 2010.

[3] S. Furby, *Land cover change: specification for remote sensing analysis*. National Carbon Accounting System, technical report no. 9, Australian Greenhouse Office, Canberra, 2002.

[4] C. Brack, G. Richards, and R. Waterworth, “Integrated and comprehensive estimation of greenhouse gas emissions from land systems,” *Sustainability Science*, vol. 1, no. 1, pp. 91–106, Oct. 2006.

[5] Z. S. Zhou *et al.*, “Terrain slope correction and precise registration of SAR data for forest mapping and monitoring,” in *International Symposium for Remote Sensing of the Environment*, pp. 1–4, Sydney, Australia, April 2011.

[6] N. Campbell and X. Wu, “Gradient cross correlation for sub-pixel matching,” in *Congress of the International Society for Photogrammetry and Remote Sensing*, vol. 7, pp. 1065–1070, Beijing, China, July 2008.

[7] N. Campbell and W. Atchley, “The geometry of canonical variate analysis,” *Systematic Zoology*, vol. 30, no. 3, pp. 268–280, Sep. 1981.

[8] H. Kiiveri and N. Campbell, “Allocation of remotely sensed data using Markov models for image data and pixel labels,” *Australian Journal of Statistics*, vol. 34, no. 3, pp. 361–374, Sep. 1992.

[9] R. MacKay and N. Campbell, “Variable selection techniques in discriminant analysis – Description,” *British Journal of Mathematical and Statistical Psychology*, vol. 35, no. 1, pp. 1–29, May. 1982.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

UNDERSTANDING THE IMPACT OF VOLUNTEERED GEOGRAPHIC INFORMATION DURING THE QUEENSLAND FLOODS

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ABSTRACT

In Australia, and the State of Queensland in particular, the recent flood events and tropical cyclones events have dramatically impacted on people's lives and damage in excess of 5 billion dollars has been reported across the state. As the varying flood events unfolded, social media and crowd sourced geographic information played an important role in keeping people informed, especially as official channels of communication began to fail or were placed under extreme load. The government's management of the Queensland floods and especially the role of the community in their assistance were widely applauded. Information and communication technologies played a critical role during the disaster and its management via the conventional communication channels such as radio, television and newspapers but also through third party social media networks such as Twitter and Facebook. This paper will review the various forms of volunteered and shared information that occurred throughout the Queensland floods and their impacts. The potential of volunteered geographic information for post-disaster assessment through damage, planning and official flood lines will be examined.

1. INTRODUCTION

The period November-March in northern and eastern Australia is marked every year by generally wet conditions and a high level of background rainfall. These background rainfall levels are generally higher in years classed as "La Niña" and lower in years classed as "El Niño". During La Niña periods, successive low pressure systems move across Queensland and cause rain, giving rise to precipitation that cannot be associated with any particular individual trough or low but rather result from the interaction of multiple weather systems. As part of the prevailing conditions, and with warm sea temperatures to the east and north of Australia at this time of year, larger weather systems including tropical cyclones form.

During December 2010 to February 2011, the State of Queensland experienced a series of damaging floods which caused billions of dollars in damage and the loss of over 20 lives. Major flooding was experienced at over 30 cities, towns and rural communities over southern and western Queensland including significant inundation of agricultural crops and mining communities. Consistent rain during the Australian spring resulted in many of the large catchments becoming heavily saturated and the larger storage reservoirs and dams reaching capacity. These conditions were further exacerbated by the presence of a number of tropical cyclones which in addition to heavy rainfall result in significant property and landscape damage due to cyclonic winds.

As the varying flood events unfolded social media and crowd sourced geographic information played an important role in keeping people informed, especially as official channels of communication began to fail or were placed under extreme load. The government's management of the Queensland floods and especially the role of the community in their assistance were widely applauded. Information and communication technologies played a critical role during the disaster and its management via the conventional communication channels such as radio, television and newspapers but also through third party social media networks such as Twitter and Facebook. People who never signed up to Facebook and Twitter started doing so and the Australian Broadcasting Commission (ABC) radio launched a link to crowd sourced reports on flooding.

This paper will review the various forms of volunteered and shared information that occurred throughout the Queensland floods and their impacts. The potential of volunteered geographic information for post-disaster assessment through damage, planning and official flood lines will be examined.

2. VOLUNTEERED GEOGRAPHIC INFORMATION AND SOCIAL NETWORKING

2.1. Volunteered Geographic Information

In the past few years the information infrastructure (primarily facilitated through the internet), the growth publicly available spatially enabled applications (such as Google Earth) and accessible positioning technology (GPS) have combined to enable users from many differing and diverse backgrounds to share geographically referenced information. This information has been termed by Mike Goodchild and others as volunteered geographic information (VGI) [1, 2]. Volunteered geographic information is not new, but it has emerged gradually from efforts in areas such as participatory GIS (PGIS) where opinions and perspectives are canvassed through GIS portals either online or within constrained environments [3].

Volunteered information in the broader context has been facilitated by the ability of web platforms to accept and to organise information in a form that is accessible to others. It may be provided as a read only type access or be subject to update, change or modification such as we see in the Wiki environments. Most of this software functionality has emerged in the past 5-7yrs which is really quite a remarkable achievement. The volunteering of the geographic dimension of information has been accelerated on two main fronts. Geographic portals such as Google Earth and others have brought geography and spatial information to the people. Digital imagery captured by an array of satellite sensors and presented through various geographic portals has enabled citizens to identify real world features and location with relative ease. The other primary source of geographic locations which are volunteered comes through the coordinates generated through the Global Positioning Systems (GPS) receivers which are now found in a range of electronic entertainment and communication devices. In particular, the integration of positioning technology and mobile internet through smart phone technologies has provided the capability for many citizens to be spatially enabled.

Volunteered geographic information represents a new and rapidly growing resource which has already illustrated a myriad of uses. Its near real-time capability has been utilised in the emergency and disaster management environments to broadcast the conditions and situation on the ground. In the absence of other rapid response mapping which invariably is delayed by days or even weeks, VGI may become critical. Recent natural disaster including the Japanese tsunami, the Christchurch earthquake and the Haiti earthquake are testament to the utility of volunteered geographic information. VGI is particularly proving to be valuable where traditional sources of fundamental spatial information does not exist or not publicly accessible[4]. Other examples of VGI deployment and utility can be found the assessment of flood damage [5], wildfire evacuation [6] and disaster response [7]

2.2. Social Networking

A social network is a network of nodes formed through relationships that may have been established through friendship, ideas, values, hobbies or other linkage mechanisms. Social networking theory is the study of these networks and the mapping of these relationships as they may apply to wide range of human organisations, from small groups to entire nations [8]. A primary reason for undertaking the study of social networks is that the understanding of the connections between individuals can be used to evaluate the social capital of the various individuals within the network. The greater the number of connections that a person has is generally indicative of the knowledge, power and influence of an individual.

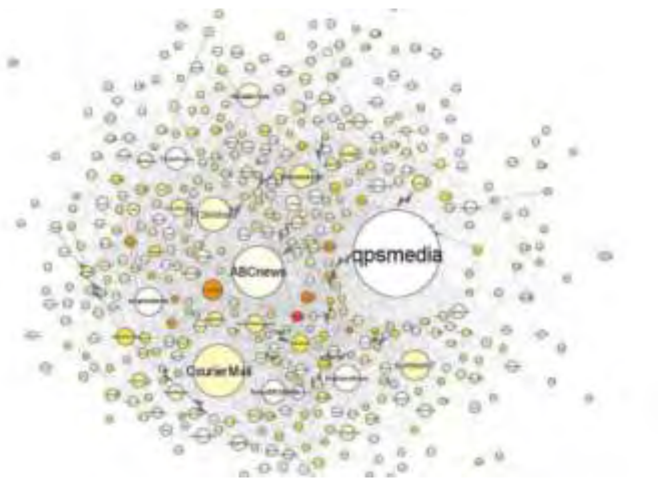

Figure 1: Mapping a Social Network

The power of social networks is of considerable interest to researchers and organisations, particularly their power to influence group or public opinion. In Australia and all over the world, community advocacy groups such as Getup (http://www.getup.org.au/) are exerting political influence on governments through grass-roots support of their network of members. It has been shown that individuals will increase their interest to participate in public processes if they are connected with others with a higher level of influence (or motivation) [9]. Citizen participation in social networking forums such as Facebook, Myspace, Friendster and others has grown dramatically in the past few years with many having over 100 million listed members.

Social networking has been identified by a number of industries and organisations as a potential contributor to a range of areas including innovation, building staff networks, solving complex problems or extending the market reach of products. By its very nature, social networking involves a series of one to one or one to many connections that require the active participation of individuals. This process of active participation can consume large amounts of time for individuals and may not be the most productive way to achieve a particular task within an organisation. Most of these systems are standalone systems that are often outside of the normal business infrastructure which can prove to be problematic. Businesses would rather restrict their information to internal clients for a variety of reasons (security, confidentiality etc.) and would prefer a system that was integrated within their existing business relationship management systems rather than outside of the business. IBM launched an internal social networking site for employees in 2007 which was designed to blur the boundaries of work, home, professional, business and fun [10]. The system, which was called Beehive, was hosted as an experimental platform for studying the adoption and usage of social networking in the workplace. Initial findings indicate that the value to employees include being able to promote ideas more effectively and to build their social capital within the organisation.

Social network analysis (SNA) is the analysis of relationships between actors in a social network and has some important implications for the sharing of information across a social network. Having power within a network may mean that an actor may potentially have better access to information, resources or social support [11]. A number of measures have been defined to quantify and classify these relationships. Terms such as centrality, closeness, betweenness and degreeness have been developed to better describe these relationships[12]. These measures can assist in defining where an actor sits within a network, where weak links exist or understanding the level of trust that may be associated with a particular actor. These measures may be used to determine if a user will share or diffuse their information or be willing to grant access to their information.

3. ROLE OF SOCIAL NETWORKING IN THE QUEENSLAND FLOODS

Social networking played a major role in keeping people informed during the January 2011 flood. The social networking service Twitter <www.twitter.com> allowed people to post and receive short text based updates about the flood in real time. Photos and videos were also able to be attached to these updates. Similarly, the website Facebook <www.facebook.com> allowed groups such as the Queensland Police Service to provide flood information updates to anyone who browsed to their Facebook page (Queensland Police Service 2011). Finally, YouTube <www.youtube.com> provided a forum for people to connect and inform through the use of user-generated and contributed videos. Harvesting of social networking data is becoming increasingly common to understand trends in social activity, movement and public affairs. Increasing techniques such as geovisual analytics or GVA are being utilised to map timelines and plot the tweets of individual or groups. This mapping and analysis can be particularly useful for crime and natural disaster assessment [13].

At the peak of the Queensland floods there were between fourteen and sixteen thousand tweets per hour on the 'qldfloods hashtag' which was used to coordinate the conversation around the flood event itself. These peaked at around the time Brisbane and the surrounding areas began to become inundated. Agencies and organisations alongside members of the community began using the Twitter platform as a place to distribute 'raw' footage, and information, but began to trust and 'follow' particular accounts. Some of the most dramatic flooding occurred in Toowoomba and the Lockyer Valley on the 10 January 2011 during a flash flood event that claimed a number of lives. The flood waters from the Brisbane catchment moved progressively towards the coast and the cities of Ipswich and Brisbane which peaked around two to three days after the flash flood events. After the #qldfloods hashtag was created people began following and tweeting as the event moved towards Brisbane and peaked during the 11 and 12 January (see Figure 2)

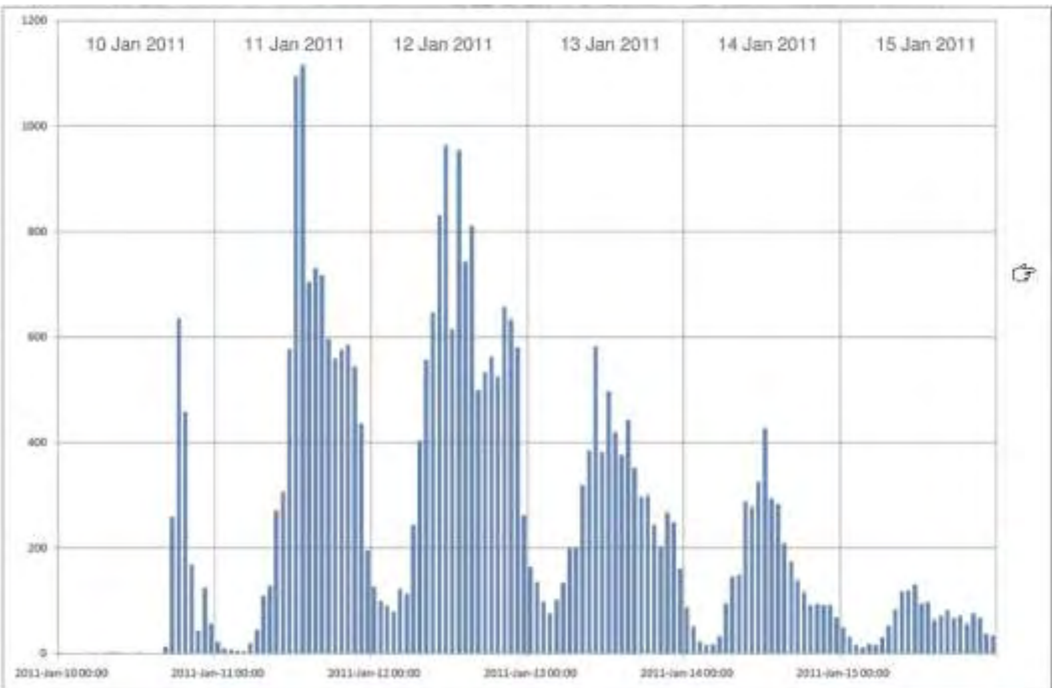

Figure 2: Tweets on #qldfloods during 10-15 January 2011 (Source: Burgess and Bruns)

By the 13 January the mainstream media had re-established their information flow and presence and people began reverting back to conventional sources of media for information. The information analysis by Burgess and Axel [14] of the use of Twitter also identified the geographic locale of the tweet and these were plotted to identify the various geographic areas discussed over time. As can be seem in figure 3 the tweets were focussed on the events in Toowoomba and Lockyer Valley regions in the first day of the flood events. However, by the second and third days the locale of discussion began to focus on Brisbane and Ipswich with the larger numbers focussing on the Brisbane area. The Queensland Police Service (QPS) had the most active and visible twitter accounts through the disaster, and many other agencies took their lead from the @QPSMedia account. Initially people were passing on the raw footage, images and videos from Toowoomba and the Lockyer Valley where the flash flooding started. Later the focus shifted to Brisbane and preparing for and responding to the floods as they were happening. Once it was no longer a news event, people were providing practical information on how to flood proof your house or how to clean it up after the flood had happened.

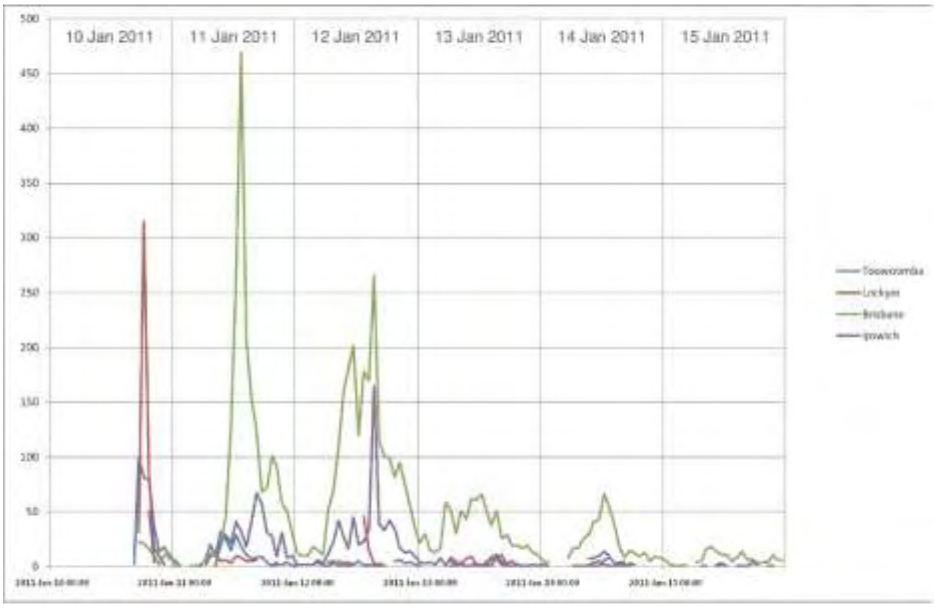

Figure 3: Locus of the Tweets for the Floods in SE Queensland (Source: Burgess and Bruns)

Ushahidi are a non-profit tech company that specialises in developing free and open source software for information collection, visualisation and interactive mapping [15]. "Ushahidi", which means "testimony" in Swahili, was a website that was initially developed to map reports of violence in Kenya after the post-election fallout at the beginning of 2008. Crowdmap is an on online interactive mapping service, based on the Ushahidi platform [15]. It offers the ability to collect information from cell phones, news and the web, aggregate that information into a single platform, and visualise it on a map and timeline.

Figure 4: Ushahidi Crowdmap of the Queensland Floods

The Australian Broadcasting Corporation launched QLD FLOOD CRISIS MAP – a crowdmap of the Queensland floods in January 2011 (see Figure 4). This crowdmap allowed individuals to send flood-related information via email, text message, Twitter, or via the website itself. This information was then available to anyone with an internet connection. This service proved to be very popular and the servers struggled at times during the crisis to keep up with the demand.

4. DISCUSSION

The use of social media provided the opportunity for people from a wide range of varying backgrounds to participate and contribute to the dissemination of information throughout the Queensland flood events. The benefits of the current technology were immediately obvious and within minutes of the event people were sending emails, photos and videos to their friends to update them about the evolving crisis. Twitter and Facebook sites facilitated the wider dissemination of the crisis to other within their network including the mainstream media. Members of the media obtained their early information from the emails, tweets and facebook postings from friends and colleagues. The media and emergency services quickly identified the power of this resource and began to establish channels to support and build their communication and information collection.

The various channels of communication provided a near real time coverage of the event that was rich in information including continuous commentary, voice, photographs and video. Early in the event the information was accurate and often breath-taking, putting all of us in the position of the observer. However, after the early stages of the event, a number spurious postings began to appear including duplications of photography and misinformation regarding the flooding events.

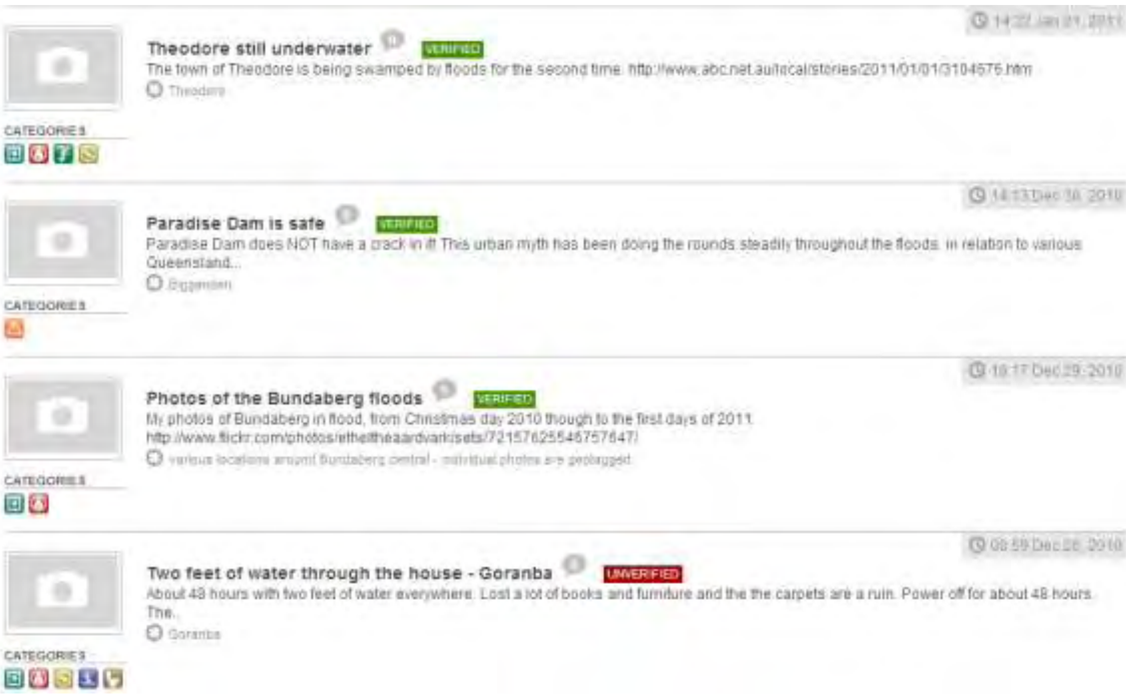

Figure 5: Moderation of the ABC Crowdmap

Verifying information is an important element of crowd mapping if you want the users to continue to have confidence in the information. This has always been one of the key issues with volunteered information and there are a number of mechanisms that can be used to improve the veracity of the information. Trust is an important commodity within these environments and a trusted source, just like a media source, is well respected by the community of users. Just like with Wikipedia, the entries are available for all to scrutinise and to edit, and so it becomes a self-moderating community.

In the case of the crowdmap users could vote up and down on the reports as they came through which improved the veracity of the information. Information that was not challenged or came from a trusted sourced was marked as verified whilst new reports or distrusted sourced are identified as unverified (see Figure 5). However, the community of users must rely on a degree of common sense with these sites and some local knowledge to validate the reports.

CONCLUSIONS

The use of social media has now added another dimension to of volunteering information and its value is undeniable in respect to its immediacy and depth of information. This case study of the use of social media and volunteered geographic information has illustrated the value of this information in disaster response. It was particularly effective in the sharing of information regarding the spreading of the flooding and alerting citizens to potential hazards. The integration of volunteered efforts into the more formal emergency management frameworks still has some way to progress, but in the absence of formal response frameworks, such as in developing countries, crowdsourced information will be critical. Although the harnessing of this information including it veracity and validation still remain a challenge, in areas where there is little or no information available, volunteered geographic information may save lives.

REFERENCES

1.Goodchild, M.F., *Citizens as sensors: the world of volunteered geography.* GeoJournal, 2007(69): p. 211-221.

2.Kuhn, W., *Volunteered Geographic Information and GIScience*, in *Volunteered Geographic Information Workshop*. 2007: NCGIA, UC Santa Barbara.

3.McDougall, K. *The Potential of Citizen Volunteered Spatial Information for Building SDI*. in *GSDI 11*. 2009. Rotterdam, Netherlands: GSDI.

4.Zook, M., et al., *Volunteered Geographic Information and Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake.* Policy Studies Organisation Commons, 2010. **2**(2): p. 7-33.

5.Poser, K., H. Kreibich, and D. Dransch. *Assessing volunteered geographic information for rapid flood damage estimation*. in *12th AGILE International Confernce on Geographic Information Science*. 2009. Hannover, Germany.

6.Pultar, E., et al., *Dynamic GIS case studies: Wildfire evaculation and volunteered geographic information.* Transactions in GIS, 2009. **13**(1): p. 85-104.

7.Goodchild, M. and A. Glennon, *Crowdsourcing geographic information for disaster response: a research frontier.* International Journal of Digital Earth, 2010. **3**(3): p. 231-241.

8.Ethier, J. (2009) *Current Research in Social Networking Theory*.

9.Boudourides, M. *A review of network theories on the formation of public opinion.* in *EURICOM Colloquium*. 2002. Nijmegen, Netherlands.

10.DiMicco, J., et al., *Research on the use of social software in the workplace*, in *CSCW'08 Workshop on Social Networking in Organisations*. 2008: San Diego, California.

11. Mori, J., T. Sugiyama, and Y. Matsuo, *Real-world orientated information sharing using social networks*, in *2005 Interantional ACM SIGGROUP Conference on Supporting Group Work*. 2005, ACM: Sanibel Island, Florida. p. 81-85.
12. Freeman, L., *Centrality in social networks.* Social Networks, 1979(1): p. 215-239.
13. White, J.J.D. and R.E. Roth. *TwitterHitter: Geovisual analytics for harvesting insight from volunteered geographic information..* in *GIScience*. 2010. Zurich, Switzerland.
14. Burgess, J. and A. Bruns. *Social Media in the Queensland Floods*. 2011 [cited 2011 20 May]; Available from: http://www.cci.edu.au/presentations/social-media-use-queensland-floods.
15. Ushahidi Website. *Ushahidi Mission*. 2011 [cited 2011 20 May]; Available from: http://www.ushahidi.com/about-us.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

FRESH EYES TO OLD PROBLEMS: EXTENDING THE DIGITAL REALM THROUGH INTERDISCIPLINARY AND COMMUNITY COOPERATION

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Word count excluding footnotes and references
3395

FRESH EYES TO OLD PROBLEMS: EXTENDING THE DIGITAL REALM THROUGH INTERDISCIPLINARY AND COMMUNITY COOPERATION

Abstract

What is the best way to empower a community and record its cultural diversity? Can the combined skills and talents of an interdisciplinary team bring historical city records into the digital realm and how meaningful can that become for the community involved?

Using examples from the inner city area of Northbridge just to the north of the CBD of Perth, this paper will draw from history, planning, GIS, and cultural heritage analysis to explore how digital data can be used to strengthen the way we analyse and create our perspectives on the world, including how Perth was shaped. Touching on the techniques for the identification, exploration and recording of the cultural heritage of Northbridge, this paper will outline some of the results and future activities being undertaken to strengthen the community and broaden global understanding of its' history via the digital realm.

Key words
digital city by using interdisciplinary community cooperation Northbridge Perth

Introduction

This paper will give a short overview on how an area of Perth, Northbridge, has over the past five years — under the auspices of the Department of Premier and Cabinet's Northbridge History Project (NHP) — recorded and dispersed online knowledge of its rich cultural heritage. The history of the area was collected, recorded electronically and made available in a fully searchable Electronic Archive (EA) online at www.northbridgehistory.wa.gov.au and through a variety of digital formats, including radio, television, podcasts and interactive compact discs. The lessons learnt from the NHP were that the investigation of Perth's city fabric is best undertaken collaboratively across professional disciplines and through engagement with the local community.

Northbridge

Northbridge is a small lozenge-shaped area, roughly a square kilometre in size which forms approximately one third of Perth's Central Area.[1] It is home to over 50 nationalities evidenced by the structures they have created — a mosque, cathedral, temples, and various churches. [2] Today it is Perth's principal restaurant and entertainment district and home to the State Theatre Centre, the Art Gallery, Western Australian Museum and the State Library.

The area was first settled in the early 1820s on swampland which was incrementally drained and used for agricultural purposes. The main railway line traversed the beds of the former swamps in 1881. By the gold rushes of the 1890s, the resultant growth of the city, increased population and expansion of rail transport, saw the area flourish as a trade and light manufacturing hub. During the twentieth century, repeated waves of migration from all parts of the globe ensured that the area reflected diverse ethnic, religious and occupational activity. A proposed inner ring road (freeway) in the 1980s saw urban blight as properties were bought to be demolished. Increased competition from suburban shopping centres and entertainment precincts and changes in the composition of the neighbourhood community, saw business confidence slump and people move away. Anti-social behaviour rose and with poor press about gangs, crime and drugs in the area, there was the feeling that Northbridge was losing its special and distinctive qualities.

More than a single discipline

Initially, the NHP conceived its role to be that of *using* the histories of the area to revitalise Northbridge but quickly discerned that, because of generational change, the custodians of the early to mid-nineteenth century history of the area were passing and the histories were on the cusp of being lost. Thus, the *modus operandi* of the NHP quickly moved from that of using history to that of *gathering* history and preserving it for others to draw upon. However, discovery of authentic voices from the past is not as simple as it seems. Frequently, the overlay of scholastic or official voices conceals other voices, less

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[1] Gehl Architects, 2009. *Perth 2009 Public Spaces & Public Life*. Perth: City of Perth and Department for Planning and Infrastructure.

[2] Jordan, K. and Collins, J., 2009. Cosmopolitan Northbridge: a changing inner-city ethnic landscape. In: Yiannakis, J. N. and Morel-EdnieBrown, F. A. eds. *Hidden Histories of Northbridge. Selected Northbridge History Project Studies Day Papers*. Bentley: Network Books, Curtin University, 249-275.

vociferous or less well recorded. Community participation was recognized as essential to the success of the Project.

The process of empowering a community can take many phases and forms to understand and engage communities in understanding their context and contributing to the development of their future.[3] In the case of the NHP, a robust community consultation was undertaken over five years.[4] Local stakeholder organisations assisted the NHP to reach their members. They included the Business Improvement Group of Northbridge (BigN); the Northbridge Rotary Club; the Hellenic Association of WA; the Italo-Australian Welfare and Cultural Association; the Italian Club; the Multicultural Services Centre of WA; the Vietnamese Temple; the Macedonian Community of WA, Polish Community of WA; Pride WA Inc.; and the Australian-Asian Association of WA. Aware that not all of those interested in Northbridge would be attending a formal Steering Committee or be affiliated with a stakeholder group, the NHP staged a number of public meetings. This enabled a wide cross section of the community to attend and discover the aims of the Northbridge History Project and to provide historical information for the Electronic Archive (EA).

What was less understood was how important interdisciplinary collaboration would become as the NHP developed. Using historians was self evident but by the end of the Project, the team not only contained historians but policy makers, geographers, spatial scientists, archaeologists, economists, cartographers, curators, theatrical designers, film makers, criminologists, religious leaders, business people, indigenous representatives, radio producers, sound engineers, photographers, graphic designers, journalists, politicians, librarians, urban planners, conservationists, musicians, authors, archivists, genealogists, tourism operators, curriculum specialists, sociologists, architects and marketing and public relations practitioners:

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[3] See Perkins, D. D. and Zimmerman, M. A. October 1995. Special Issue: Empowerment Theory, Research, and Application. *American Journal of Community Psychology,* 23. for a range of papers dealing with community engagement and empowerment.

[4] For a detailed account of the model, process and connection to community see: Morel-EdnieBrown, F. A. 2011. Community engagement, heritage, and rediscovering a sense of place in Northbridge, Perth, Western Australia. *International Journal of Asia-Pacific Studies,* 7, 1-25. .

An annual Northbridge History Studies Day responded to Article 13c of the Faro Convention on Cultural Heritage to 'encourage interdisciplinary research on cultural heritage, heritage communities, the environment and their inter-relationship'.[5] Leading scholars presented diverse investigations about Northbridge in terms of its Aboriginal heritage, natural environment, urban form, migrant entrepreneurship, heritage places, labour history, film and art, specific cultural groups, city policy, deviance and recollections of it being a place of difference and adventure.[6]

The NHP introduced community presenters appearing beside academic presenters and, although met with some resistance at first, proved worthwhile for both groups. The academic researchers learnt first-hand about a rich and diverse area and the community respected the research that was being undertaken at a high level about their histories:

> "The stimulus that was afforded by the Project to the Jewish community to document its important history within the Northbridge precinct was a wonderful opportunity that almost certainly would have otherwise been lost to it. As a former President of the Jewish Community Council of Western Australia, I am glad that I was able to present some of that history at one of the Northbridge Study Days and that an enhanced version of the talk was published in the first Northbridge volume. The recording of the rich history of all the communities of Northbridge who have together contributed to building our WA society is a story well worth telling." *Dr Keith Shilkin AM, Fmr President of the Jewish Community Council of WA, Member Jewish Steering Committee*

> "On behalf of the Polish community in Perth we feel that we owe you a debt of gratitude for the way you managed to open our hearts and our minds to the possibilities of remembering and accepting the history of our parents and grandparents and be able to pass it onto our young generation. Many of their accomplishments spanning over a hundred years were uncovered and will be

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[5] Council of Europe, 2005. *Framework Convention on the Value of Cultural Heritage for Society.* Faro, Portugal. Article 13c.

[6] For a full list of the topics and presenters of papers see Department of the Premier and Cabinet, 2010. *The Northbridge History Project Report 2005-2010.* Perth: www.northbridgehistory.wa.gov.au. available online at www.northbridgehistory.wa.gov.au

> available in the electronic archives to be used in the future.” *Halina T. Szunejko OAM, President, Polish Community Council of WA*

This interdisciplinary research broadened the understanding of Northbridge:

> “The Northbridge History Studies Days are quite outstanding – even the abstracts show how our understanding of Perth has been deepened and broadened since the Studies Days began. I congratulate the Northbridge History Project on its contribution to the history of Perth.” *Emeritus Professor of Public History, Tom Stannage*

> “I have been extremely impressed by the excellent planning, development, progress and outcomes of the Northbridge History Project. It has made a most significant contribution to our understanding of the history of Perth. The collection has immense potential for further research projects.” *Jenny Gregory AM, Professor of History, The University of Western Australia*

So what do interdisciplinary techniques bring to analysis of urban fabric? Some of the opportunities are obvious: different ways of presenting and dispersing information; different analytical tools; using technologies differently by combining knowledge; and, developing bonds and connections between people in different professions to stimulate new collaborations (artists etc) and new audiences (GIS community, history, archaeology etc). Some of the challenges are less so: different methodologies of data collection and verification by different disciplines; the use of incomplete and contradictory data to contextualise human actions; fuzziness of technical data when working with historical sources; issues of recollection and memory being imprecise or erroneous, and, professional parochialism. Nevertheless, the interdisciplinary approach bore fruit as a diverse range of people met, discussed and researched together about the area:

> “...I was struck by the importance that people place on acknowledging and celebrating the past and the things they have shared with others, whether that’s work or study. The spirit of these shared things does endure beyond buildings to linger in the places around us – as it does here in Northbridge – but we all have a role in maintaining and honouring these collective memories to realise their true value to our communities.” *Neil Fernandes, Managing Director Central Institute of Technology*

Being digital

It is unlikely that this interdisciplinary and inter-community collaboration would have been as effective if the structure of the Project had not been digital in its focus. Being digital assisted and encouraged the free interchange of materials across disciplines and different investigative processes to be brought to bear, simultaneously, on multiple copies of the original. Had only originals or poor quality copies been only available this would not have occurred.

At the time of its establishment of the NHP, the digitization of historical records was comparatively new. Therefore, the NHP developed its own standards for creating the EA, based on comprehensive research. The digital process began as decisions were being made as to how to record and present materials in the Project and it continued throughout resulting in a simple but fully searchable online electronic archive of primary and secondary sources of photographs, maps, plans, oral histories (and associated transcripts), displays and documents. High quality, high resolution scans of images and documents and high quality voice recordings (48kHz, .wav files) were established as policy on the basis that lower quality files could be cut from these master copies for a variety of uses. The standards have subsequently been adopted by other collecting agencies. However, all images and voice recordings in the online Electronic Archive were supplied in low resolution for faster download.

As the NHP only took electronic copies of the sources, the originals remained with the donor. As a result the Project was given access to many sources which had never before been made publicly available. There was a high level of commitment to the EA, brought about in part because the use of digital collection, rather than gathering original from family collections, meant that people did not feel threatened that original objects would be removed from family situations. This gave the EA incredible diversity and richness. The earliest photograph obtained, not previously in a public collection, was 1883; the latest 2010. Interviews ranged from four minutes through to five and a half hours; the youngest interviewee was nine, the eldest 103. Images and documents were scanned at high resolution (1200 or 2400 dpi) 'on the spot' at community events or the donor's homes (using portable scanners). As a result, donors felt very comfortable in providing access to family photographs and documents.

There was a sense in the community that these histories were being preserved for the sake of Northbridge and that the digital presentation of the material would allow more voices and interpretations to be made than would a more static presentation such as a monograph. In an area where there has sometimes been a patchy relationship with government agencies, this process helped to build trust, commonality and respect across different groups involved in the NHP.

The use of digital sources also provided the opportunity for some groups to share stories outside the formal NHP structure but feed into it. Social media was an important tool for the Gay and Lesbian community to collect their histories of Northbridge. The community established a MySpace page in 2007 and a Facebook group ‘The Gay & Lesbian Northbridge History Project’ in 2008 to reach a younger demographic and increase interest in the gay and lesbian history of Northbridge. The group had 366 members, 18 discussion topics with 137 posts, 381 photographs and 27 videos. This discovery of the importance of the area then influenced other decisions:

> “Because of this, Northbridge is where we intend to stay (and we had thoughts of moving Connections), it is where we intend to develop new business and where we intend to continue to work to develop a community that is culturally rich, diverse and indicative of the city we aspire to live in.” Tim Brown, Managing Director Connections

The creation of a fully searchable EA was both a privilege and a luxury as the NHP staff didn’t have to filter or interpret material before putting it into the EA, other than to ensure it related to Northbridge. Therefore, a wide range of primary and secondary sources were made available for use generally unfettered by pre-determined curatorial classifications or ranking of materials.

The structure of the EA was, and is, very simple. All of the material was documented in a Microsoft Excel database and presented online via fully searchable pdf's. Material can be searched by media or group or across all records (pictures, transcripts, documents and transcripts of audio files) using any search term. Alternate spellings can be included for names and places and indexing is not artificially constrained by staff selections made in advance. For example a search on the word "milk" will bring up resources including oral histories, photographs and documents from which to explore the various memories of cows, kindergarten and war-time propaganda photography. In the future the search function will be GIS enabled.

By being a digital archive, available online, the NHP not only recorded the historical information about the area; it gave new perspectives to the current community on their lives and those of their forebears and moved beyond the boundaries of the area it was set up to service: ‘this is a wonderful project. It is very important to preserve the history of the area and all the communities. Thank you for offering me the opportunity to contribute to the testimonies of the Jewish Community in Perth.’, *Shoshana Mittelberg, Israel*

Mapping Northbridge

Although a number of different disciplines worked cooperatively with the NHP, the introduction of mapping and spatial analysis of the area proved both exciting and revealing. From simple mapping exercises with the community to GIS enabled analysis, new information about Northbridge was gleaned and people began to think spatially about their community and its activities. This created a different perspective on the sense of place of the community as they recalled, recorded and mentally reconstructed the geography of their lives and began to understand how they were both influenced by, and influencers of, the physical qualities of the area.

Mapping introduced a whole set of new techniques for contextualising and understanding the spatial relationships in the area. This ranged from a GIS enabled analysis of the swamp history of the area and the development of the area of Northbridge and its relationship to the urban form of Perth,[7] to mapping the places of importance to the different communities on an oversized map,[8] memory mapping,[9] and establishing work on *Virtual Perth,* a spatially enabled intergovernmental and interdisciplinary research portal to integrate datasets from State Government and key industry partners.[10]

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[7] Morel-EdnieBrown, F. A., 2009b. The Swamp Stealers: Envisaging the Swamps of Northbridge. *In:* Yiannakis, J. N. and Morel- EdnieBrown, F. A. eds. *Hidden Histories of Northbridge. Selected Northbridge History Project Studies Day Papers.* Curtin University Bentley: Network Books

[8] Department of the Premier and Cabinet, 2010. *The Northbridge History Project Report 2005-2010.* Perth: www.northbridgehistory.wa.gov.au. 37-39.

[9] Ibid. 40.

[10] Ibid. 70.

Minute investigation of the town plans of Perth and the changes in the former swamplands over time were mapped in GIS and clearly showed both the diminution in the extent of the swamps over time their influence on the town planning of the city. To accommodate the shape of the swamps, the regular form of the town grid north of Wellington Street was discovered to have been disrupted. Future street alignments in Northbridge (and as far north as Vincent Street) would respect this alignment, even after the drainage of the swamps was completed.[11] This alignment resulted in a more pleasant winter micro-climate because of the orientation of the streets, permitting better solar penetration in winter and subsequently underpinning the development of Northbridge as Perth's *al fresco* dining area. The revelation that the very streets of Northbridge had historical context in the former swamps reinforced the communities' sense of place and geographic understanding of the topography of the area.

Further mapping was done of Northbridge by using the locational data listed in land transactions — a source very familiar to historical research but not necessarily though of by historians as spatial. These data were collated into a database and their spatial characteristics mapped in GIS. Although a comparatively simple use of GIS, the layering capacity of GIS was able to visually render complex land transactions that occurred rapidly in Perth, including the subdivisions and amalgamations of town lots, and different ownership patterns over time. The interdisciplinary strength of this approach has provided new and important information about the formation of the area and the types of activities undertaken there in the nineteenth century.

This gave historical context to the records that were being collected from the community for inclusion in the NHP, most of which were from the twentieth century. The community began the process of thinking spatially about Northbridge and, in doing so, discovered relationships within their community that they had not previously thought existed. They mapped places of importance and the routes that they took in and out of the area and

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[11] For a more detailed analysis of the impact of the swamps in Perth see Morel-EdnieBrown, F. A., 2008. Tethered Antipodes: Imperial impress in central Perth, Western Australia. *In:* Limb, P. ed. *Orb and Sceptre: Studies in British Imperialism and Its Legacies.* Melbourne: Monash University ePress, 04.01-04.43.and for the use of GIS in this context see Morel-EdnieBrown, F. A. 2009a. Layered landscape: the swamps of colonial Northbridge. *Social Science Computer Review*, 27(3), doi:10.1177/0894439308329765..

documented their neighbourhood as a defined and special place in the cityscape. This reinforced their sense of place and brought back connections and subtleties in recollection which were subsequently reformed as they walked the streets and made new mental associations to places in the area. To supplement this a process of ‘memory mapping’ of early childhood mapping (a sociology-based technique, developed by the author) was undertaken which reinforced the spatial and pre-verbal understandings of the area.
Further GIS based mapping is envisaged as part of a proposal to create a spatially enabled research portal for Portal called *Virtual Perth*. This collaborative portal will bring together a wide range of interdisciplinary practitioners, complement the use of existing datasets and be used to cross-interrogate datasets to extend the body of knowledge in Western Australia. *Virtual Perth* will create a global presence for Perth online and interpret historical, current and ‘future’ Perth by using geographic information systems (GIS) and to integrate datasets from State Government and key industry partners. Local partners are the Department of the Premier and Cabinet, Department of Planning, Landgate, WALIS, City of Perth, Town of Vincent, Heritage Council of WA, State Records Office of WA and State Library of WA, Curtin University, The University of Western Australia, and Murdoch University. Transfrontier partners are Sydney University and the University of California Berkeley's Electronic Cultural Atlas Initiative (www.ecai.org). A decision as to the success of the application to the ARC is pending. Should the application be successful the Department of Planning will become the lead government agency.

Conclusion

The interdisciplinary collaboration during and beyond the NHP means it did not suffer from a mono-cultural view. It was able to include diverse and extended views of the same materials — each discipline brought a different set of questions to the material and viewed it as having different possibilities to increase their own understandings — and saw different ways of interpreting the area. As such NHP avoided becoming the one-size-fits-all vision of the area and allowed multiple voices to be heard. In the final analysis, it was this multiplicity that gave the NHP its richness and respect for the cultural fabric of the area.

> “I am deeply impressed by the vision, scope, and real-world results of the Northbridge History Project. It is one of the finest examples of successful community engagement in heritage that I have ever seen. This is heritage intended

not just for tourism or historic preservation, but also to improve the life of a community and to recognize the dignity of its people and their memories. No small achievement. In doing so, the Northbridge History Project offers a valuable model for multicultural urban communities throughout Australia and indeed everywhere in the world." *Neil Silberman, President, ICOMOS International Scientific Committee on the Interpretation and Presentation of Cultural Heritage Sites*

Future work across disciplines will continue using the NHP because it has been constructed as a free online electronic archive. As such, its resource is available to be mined. Researchers in the fields of history, anthropology, archaeology and psychology are currently researching the area using the archive. Artists and curators are creating exhibitions and artworks based on its material; the Australian Broadcasting Commission's Radio National recently did an hour-long programme on the area;[12] curriculum materials teach the history of the area to the first four years of high school, and the area will be subject to investigation in an international archaeology conference in 2013.

References

Australian Broadcasting Corporation, 'Rediscovering Northbridge' [Radio], Annie Thompson (Producer), *Hindsight*, ABC Radio National, Perth, 17 April 2011 http://www.abc.net.au/rn/hindsight/stories/2011/3180244.htm, accessed 18 April 2011, 1500 WST (GMT+8:00).

Council of Europe, 2005. *Framework Convention on the Value of Cultural Heritage for Society.* Faro, Portugal.

Department of the Premier and Cabinet, 2010. *The Northbridge History Project Report 2005-2010.* Perth: www.northbridgehistory.wa.gov.au.

Gehl Architects, 2009. *Perth 2009 Public Spaces & Public Life.* Perth: City of Perth and Department for Planning and Infrastructure.

Jordan, K. and Collins, J., 2009. Cosmopolitan Northbridge: a changing inner-city ethnic landscape. *In:* Yiannakis, J. N. and Morel-EdnieBrown, F. A. eds. *Hidden Histories*

[12] *Rediscovering Northbridge* [Radio], Australian Broadcasting Corporation, Annie Thompson (Producer), Hindsight, ABC Radio National, Perth, 17 April 2011 http://www.abc.net.au/rn/hindsight/stories/2011/3180244.htm, accessed 18 April 2011, 1500 WST (GMT+8:00)

of Northbridge. Selected Northbridge History Project Studies Day Papers. Bentley: Network Books, Curtin University, 249-275.

Morel-EdnieBrown, F. A., 2008. Tethered Antipodes: Imperial impress in central Perth, Western Australia. *In:* Limb, P. ed. *Orb and Sceptre: Studies in British Imperialism and Its Legacies.* Melbourne: Monash University ePress, 04.01-04.43.

Morel-EdnieBrown, F. A. 2009a. Layered landscape: the swamps of colonial Northbridge. *Social Science Computer Review,* 27(3), doi:10.1177/0894439308329765.

Morel-EdnieBrown, F. A., 2009b. The Swamp Stealers: Envisaging the Swamps of Northbridge. *In:* Yiannakis, J. N. and Morel- EdnieBrown, F. A. eds. *Hidden Histories of Northbridge. Selected Northbridge History Project Studies Day Papers.* Curtin University Bentley: Network Books

Morel-EdnieBrown, F. A. 2011. Community engagement, heritage, and rediscovering a sense of place in Northbridge, Perth, Western Australia. *International Journal of Asia-Pacific Studies,* 7, 1-25.

Perkins, D. D. and Zimmerman, M. A. October 1995. Special Issue: Empowerment Theory, Research, and Application. *American Journal of Community Psychology,* 23.

PGIS Supported Knowledge Based Participation and Evidences of Empowered Community Members

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Abstract
In much of Botswana's rural population, formal business ethic is not common and the business environment contains fragmented and incomplete information. Under such mainly agrarian economies, the villagers do not know where the customers for their produce are, there is limited technology and often the farmers are not aware of the potential benefits from their agro-businesses. Many people are also not aware of the supportive policy frameworks, the agricultural programs/projects that the government has set up for them and the attendant financial support programs that are intended to implement the programs. The villagers participate more in social welfare programs from which they do not earn enough to live dignified lives. Participation and empowerment paradigms have been used in development programs to foster rural community development. However, many national and international development projects have been implemented with insufficient understanding of participation and empowerment processes. Using participation as learning and empowerment as informed participation within community group interactions, this paper presents the use of participatory action research implemented through participatory geographic information system (PGIS), to facilitate community learning and the construction of a PGIS based knowledge repository. The knowledge repository addressed issues of fragmented and incomplete information and also served more to facilitate knowledge construction, encourage local innovation and forged links with the local community development institutions as well as district and central government institutions.

Keywords*: participatory geographic information systems, action research, participation, knowledge construction, empowerment, rural community development*

Participation, when implemented intentionally as a learning strategy (Elkjaer 2003) can impart knowledge (Breu 2001), especially where people are involved in personally meaningful actions (Baum, MacDougall, and Smith 2006). The process of gaining knowledge involves acquiring the understanding of the theories that are involved in a particular knowledge area (Banks 2009; Oxenham et al. 2002) as well as gaining the practical hands on experience (Kolb, Boyatsis, and Mainemelis 2000) of carrying out the tasks. Within rural communities where communication is mainly oral, conversations act as the media for experiential learning (Baker, Jensen, and Kolb 2005) and generating knowledge. The acquisition of knowledge in turn imparts capabilities and skills (Oxenham et al. 2002). Capabilities and skills then build human capital as personal power within individuals, this individual power is then deployed within community groups to produce the more effective collective power (Chambers 2006). Participatory action research such as one supported by participatory geographic information systems (PGIS) can provide opportunities for empowerment (Corbett and Keller 2005; Kesby 2005).

Empowerment is considered to be a social process whereby individuals, communities and organizations gain control over their lives by changing their social and political environment in order to improve equity and quality of life (Peterson and Hughey 2004). Godfrey et al. (2002) also refer to power when they view capacity as the abilities of individuals and groups "to perform functions, solve problems and set and achieve goals" (Godfrey et al. 2002, p356) Yet in order for communities to achieve such empowerment, they need to have basic knowledge about how democratic, economic and political processes are carried out, for example Barber (2003) notes that within a globalization context democracy has a tendency to ascribe malevolence and anarchic behaviour to individuals and organizations. It becomes critical therefore for individuals to learn and acquire knowledge so that together they can constitute empowered, knowledgeable and intelligent advocacy groups for their communities (Chambers 2006; Peterson and Hughey 2004). Such empowerment is necessary given the poor performance of the international development project since the 1950s (Ellis and Biggs 2001; Black 2007).

Misunderstandings of Participation and Empowerment

Despite its long history since the 1970s (Uphoff 2000), empowerment, whose literal translation implies the process of imparting power to someone by an external other who professes to consider others as powerless is a patronizing act from the onset. Henkel et al.(2001) view empowerment as subjugation to modernity and the global market and consider participation to be a form of governance. Viewed in this negative sense, most self-directed individuals normally object to and rebel against such imposed assistance (Mathers, Parry, and Jones 2008). Dinham (2005) refers to such imposed imparting of power when he questions whether in Bristol's New Deal for Communities development strategy, the citizens are empowered or overpowered. Similarly, MacLeavy (2009) notes partnerships that constitute tokenistic organizations that do not represent the multiple interests of people. Empowerment cannot be properly understood and facilitated until a more appropriate understanding of the participation that enacts it is realized. Stephens (2007) discusses dominant forms of participation which advantage the more powerful groups and which do not consider the different levels of participation, whereas there are other forms of participation which consider the social psychological conceptualizations such as practicalities, everyday requirements and purposes of social life. Moreover, empowerment cannot be understood without having a clear understanding of power (Gaventa 2005), Gaventa refers to the spaces, places and dynamics of power as they relate to the structures of geographic scales, access to the inner decors of power strongholds wherein power can be visible, deliberately hidden or invisible.

The problem with current conceptualizations of participation is that the theories are flawed in the sense that the evaluation of participation which is intended to discover whether empowerment has taken place, often evaluates the achievement of goals rather the outcomes and consequences of participation (Baker 2000). Ultimately, participation is a knowledge divide between the North and the South (Karlsson 2002; Karlsson, Srebotnjak, and Gonzales 2007) where the south becomes invisible in global governance, where internationalized knowledge generated from the North is less representative of conditions in the South and where consequently the South cannot participate in global governance on equal terms. Thus participation is not about economic poverty only, it is also about the poverty of influence (Najam 2005) and by the same token so is empowerment not just about increased participation in development initiatives and access to the spaces and places wherein power is enacted, it is also fundamentally about rights to define and shape the spaces of power. If ultimately participation is about access to knowledge then information systems such GIS and particularly participatory geographic information systems (PGIS) have a key role in implementing truly empowering participation (Bugs 2009; Corbett and Keller 2005; Kesby 2005), especially within rural community development initiatives.

Deriving a PGIS Framework to Effect Participation and Enhance Empowerment

A PGIS framework called the Rural Community Knowledge PGIS (RCK-PGIS) framework was developed with the active input of a rural community. The RCK-PGIS framework itself was based on a number of related participatory frameworks. These frameworks include the following: a) Enhanced Adaptive Structuration Theory (Nyerges, Jankowski, and Drew 2002), b) Spoleto framework (Rugg 2001), c) the geo-spatial ontology (Sieber and Wellen 2007), d) the participatory community design framework (Pipek et al. 2000), e) the integrated systems for knowledge management (Allen et al. 2001), f) an information systems adapted sustainable livelihoods framework (Duncombe 2006) and g) the information systems for emancipation (Kanungo 2004). Figure 1 shows the final framework which was developed after three field trips lasting 9 months, 4 moths and 2 months respectively. The first field work covered the data analysis and data collection, the second field work covered the feedback workshops and the last field work covered the evaluation of the framework.

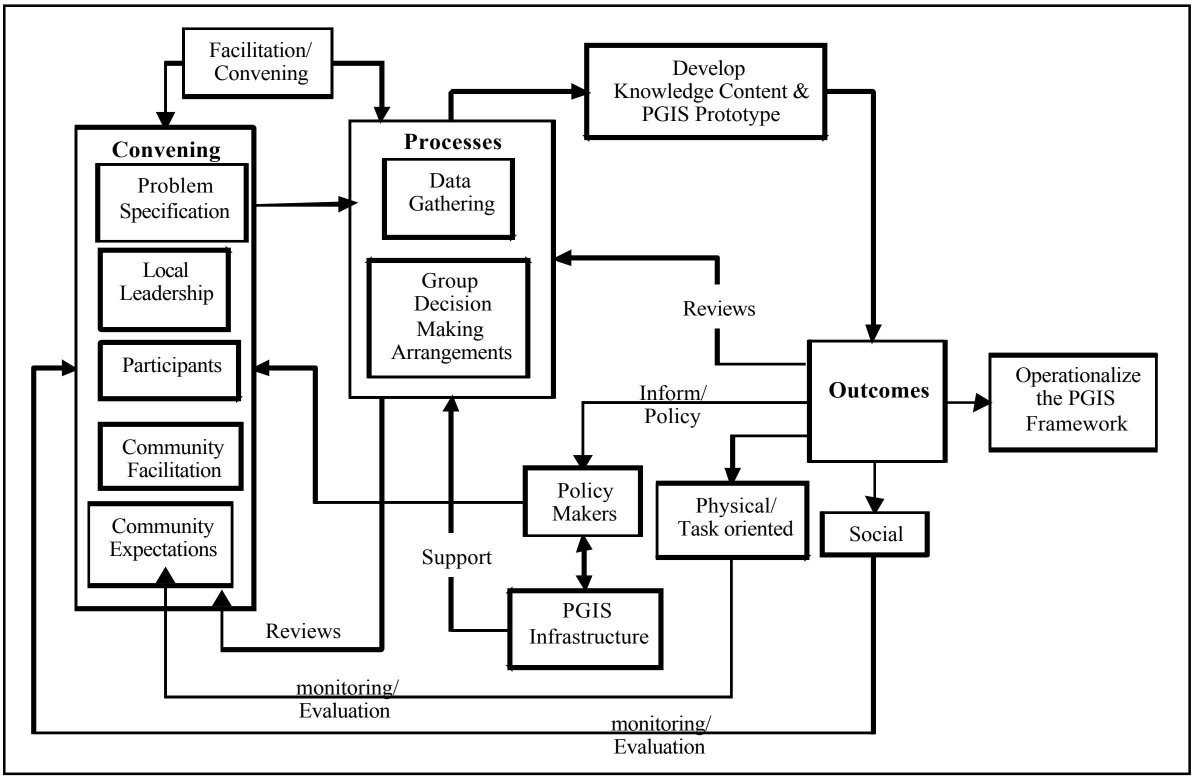

Figure 1 The Rural Community Knowledge PGIS framework

The key to meaningful participation lay in preparing the community to participate by basing all communication with work based interactions. The village leaders assumed the role of mobilizing the community by convening public village meetings, selecting the convening venue and the village participants. The village participants included the village development committee (VDC) which acted as co-management of the research project and the village trainees who did the actual work. The activities were based on 'on the job training' which covered: a) basic computing, b) business process modelling, c) basic introductions to GIS, learning the GIS software, georeferencing and on screen digitizing to develop the village plots map which subsequently served as the core data set for the village knowledge repository, d) review of draft social survey questionnaire, its testing and its subsequent administration through personal interviews, e) administration of an attitude scale, f) feedback workshops which included all the villagers who were interviewed and g) the evaluation workshops. The evaluation of the RCK-PGIS framework used the definition of empowerment that related to the acquisition of capabilities which empowered action. A score of '1' represented capability which was not sufficient to empower action. A score of '2' denoted capabilities which were likely to empower action and a score of '3' which ensured capability to act. The evaluation also used combinations of individual and collective empowerments to conclude whether community empowerment was achieved or not, where successful community empowerment was judged on the successful achievement of collective capabilities.

Some of the Outcomes of the PGIS Approach as Evidences of Empowerment

The first outcome which emerged was the decision by the village community to adopt the research concept of knowledge to improve livelihoods at the household level by proposing and working to develop their own knowledge centre which they called "*Mashego a Lobu*" Knowledge Centre (MLKC), this means the "pan's blessings". This indicated deliberate reflection by the community leaders, and the deliberation was followed by action to institutionalise the MLKC. The key to this surprising response

by the community lay in their appreciation of being recognized as knowledgeable individuals who had important contributions to make from their knowledge of their own social system. Figure 2, which shows the vision of the MLKC information flow infrastructure, that is VDC offices as main centre and ward based data collection centres forms the main basis of the village development initiative.

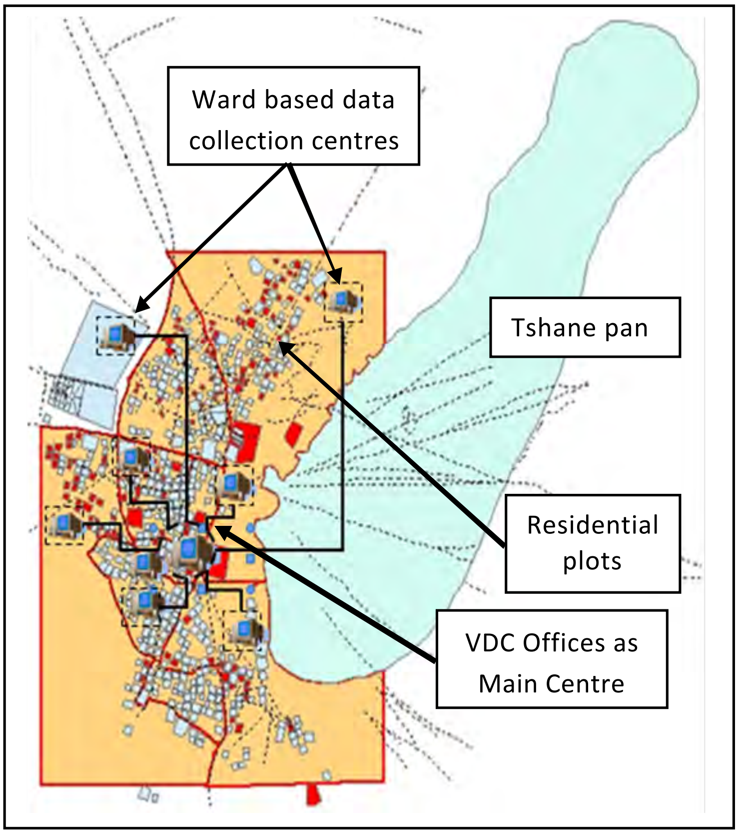

Figure 2 Tshane RCK-PGIS Wireless Information Flow Infrastructure

The vision of the information flow structure serves also as the vision of the village which visualizes a future where all households will have dignified shelters with water and electric power connections. The information structure requires the formalization of the ward centres, their building (currently mainly open spaces) and the mapping of the ward boundaries. Improved household shelter has been mandated as the responsibility of the ward heads. Thus the anchoring role of knowledge repositories has created village groups, the village ward leaders, the village trainees as the PGIS users, a number of goat project owners who through emulating a successful goat project by one of the village trainees are beginning to talk about forming a goats owners group. Moreover, the trainees have begun prioritizing the acquisition of residential plots and the building of better housing, an activity that is being copied by other members of the community. The information flow infrastructure also represents the avenue through which the community development institutions (CDIs) and central government can interface with the village community. In addition, the presence of development projects which were produced by the village community outside the CDIs intervention processes creates an opportunity for the CDIs to participate in community initiated projects.

The results of the evaluation exercise appear in Figure 3 which shows the participation scorings over the participation activities which range from the convening to the participation outcomes. The results show empowerment for the convening, facilitation, data capture, PGIS evaluation and potential operationalization of the RCK-PGIS framework. Lack of empowerment was revealed at data structuring and the livelihood outcomes. The failure of empowerment at the more technical components and the livelihoods was expected. For the data structuring activity, it was considered to result from activities carried out away from the site but also from low levels of education and lack of ICT activities in the village. Failure to secure sustained livelihoods resulted from lack of financial resources to implement the business plans and lack of skill in sourcing funding as well as lack of skill in filling the application forms.

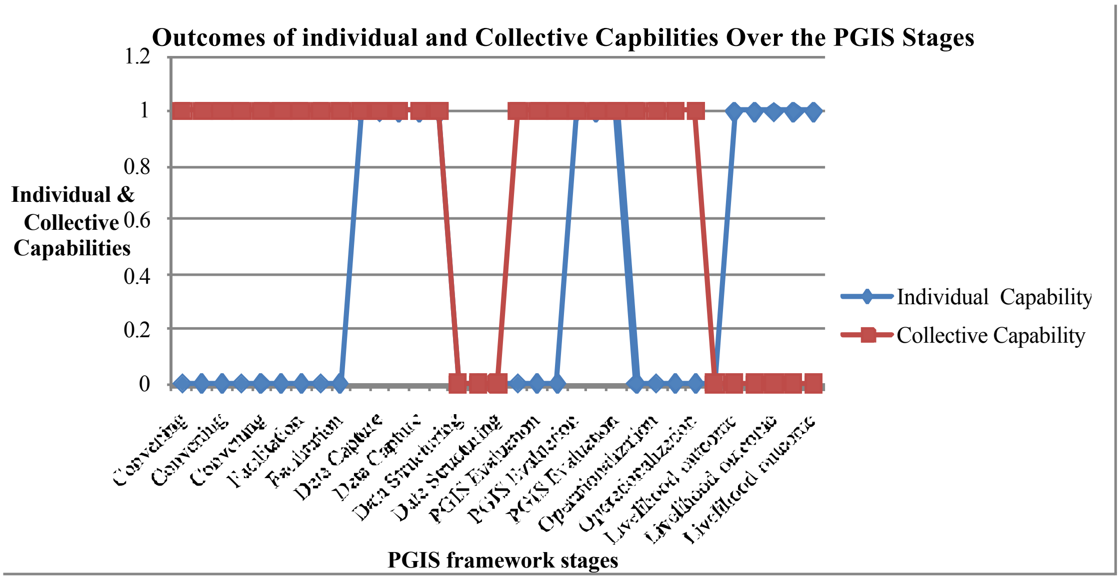

Figure 3 Outcomes of the individual and collective capabilities over the PGIS stages

The research project is currently over, however, the collaboration work with the village community continues, where the task now is to operationalize the innovative ideas which have been generated and essentially taking on the task of building the MLKC. The indication is that the community still has much learning to do, participation and empowerment processes do not honour research bound time scales, they are long and quite often lifetime journeys.

Conclusions

The first nine months of field work showed clearly that even for a national member of a community, it takes time to create a productive collaborative research partnership. This results from a long history of exploitation that the village communities have gone through. Mathers, Parry, and Jones (2008) note that communities use non-participation as a survival strategy against this long term multiple disadvantage. It is therefore wise for external experts to be humble and to take time to find out what the community knows with regard to proposed intervention strategies and who their knowledge experts are.

When a participatory research method is followed and a training strategy that relates directly to local livelihoods is pursued, village community members can engage successfully in collaborative research and derive benefits from it. This requires that a needs assessment should precede the actual intervention so that the intervention is aligned with the community needs.

A participatory intervention strategy that is perceived by the local community to present balanced power relations such as recognizing and expecting contributions of local knowledge, pacifies and imbues the community with the confidence to participate more meaningfully and enhances their chances of achieving the right to define and shape the participation spaces and places. It is useful therefore to have knowledge of the village power dynamics in order to be able to navigate safely through the hidden networks of power and avoid costly mistakes.

Failure to achieve empowerment at data structuring and livelihood procurement stages of the deployment of the RCK-PGIS framework indicates the presence of activities that need a stronger local community knowledge base. Such cases indicate the need for other institutional interventions, such as appropriate education policies and the placement of enabling ICT infrastructure. Participation and empowerment strategies therefore call for integrated and planned interventions whose plans go beyond the standard project time scale.

Although village community members may appear humbled, silenced, made to feel inferior to external expertise and constantly exploited, it does not mean that they are culturally weak, pragmatically ignorant or totally unskilled. On the contrary, rural communities are survivors and can understand ICTs if they are presented in a form that they can consume and through a process that they can participate in, the conceptualization of the Mashego a Lobu Knowledge Centre is a clear evidence of this. The intervention strategies therefore need to identify activity roles that the village community can occupy, their involvement should not appear to be an after-thought as this will be perceived by the community and cause conflict.

References

Allen, W., O. Bosch, M. Kilvington, J. Oliver, and M. Gilbert. 2001. Benefits of collaborative learning for environmental management: Applying the Integrated Systems for Knowledge Management approach to support animal pest control. *Environmental Management* 27 (2): 215-223.

Baker, A. C., P. J. Jensen, and D. A. Kolb. 2005. Conversation as experiential learning. *Management Learning* 36 (4): 411.

Baker, J. L. 2000. *Evaluating the impact of development projects on poverty: A handbook for practitioners*. Washington D.C.: World Bank Publications.

Banks, J. A. 2009. Knowledge Construction and the Education of Citizens in Diverse Societies In *InterkulturelI Pedagogik*. Gotenborg Convention Centre, Gothenburg, Sweden.

Barber, B. R. 2003. *Strong democracy: Participatory politics for a new age*: Univ of California Pr.

Baum, F., C. MacDougall, and D. Smith. 2006. Participatory action research. *British Medical Journal* 60 (10): 854.

Beierle, T. C., and D. M. Konisky. 2000. Values, Conflict, and trust in Participatory Environmental Planning. *Journal of Policy Analysis and Management* 19 (4):

Black, M. 2007. *The no-nonsense Guide to International Development*. Oxford, U.K.: New Internationalist.

Breu, K., and J. Peppard. 2001. Participatory Paradigm for Applied Information Systems Research. In *The 9th European Conference on Information Systems*. Bled, Slovenia, June 27-29, 2001.

Bugs, G. T. 2009. The intersection of people, technology and local space. PPGIS and Web in practice for participatory planning.

Chambers, R. 2006. Transforming Power: From Zero-Sum to Win-Win? *IDS bulletin* 37 (6): 99.

Corbett, J. M., and C. P. Keller. 2005. An analytical framework to examine empowerment associated with participatory geographic information systems (PGIS). *Cartographica: The International Journal for Geographic Information and Geovisualization* 40 (4): 91-102.

Dinham, A. 2005. Empowered or over-powered? The real experiences of local participation in the UK's New Deal for Communities. *Community development journal* 40 (3): 301.

Duncombe, R. 2006. Using the livelihoods framework to analyze ICT applications for poverty reduction through microenterprise. *Information Technologies and International Development* 3 (3): 81-100.

Elkjaer, B. 2003. Social learning theory: learning as participation in social processes. In *The Blackwell handbook of organizational learning and knowledge management*, ed. M. Easterby-Smith and M. A. Lyles, 38–53. Malden, Oxford and Carlton: Blackwell Publishinf Ltd.

Ellis, F., and S. Biggs. 2001. Evolving themes in rural development 1950s-2000s. *Development Policy Review* 19 (4): 437-448.

Gaventa, J. 2005. Reflections on the Uses of the "Power Cube Approach" for Analysing the Spaces, Places and Dynamics of Civil Society Participation and Engagement. *Prepared for Dutch CFA Evaluation 'Assessing Civil Society Participation as Supported In-Country by Cordaid, Hivos, Novib and Plan Netherlands*:

Godfrey, M., C. Sophal, T. Kato, L. Vou Piseth, P. Dorina, T. Saravy, T. Savora, and S. Sovannarith. 2002. Technical assistance and capacity development in an aid-dependent economy: The experience of Cambodia. *World Development* 30 (3): 355-373.

Henkel, H., R. Stirrat, B. Cooke, and U. Kothari. 2001. Participation as spiritual duty; empowerment as secular subjection. *Participation: the new tyranny?* : 168-184.

Kanungo, S. 2004. On the emancipatory role of rural information systems. *Information Technology & People* 17 (4): 407-422.

Karlsson, S. 2002. The North-South knowledge divide: Consequences for global environmental governance. *Global Environmental Governance; Options and Opportunities. New Haven: Yale Center for Environmental Law & Policy*:

Karlsson, S., T. Srebotnjak, and P. Gonzales. 2007. Understanding the North-South knowledge divide and its implications for policy: a quantitative analysis of the generation of scientific knowledge in the environmental sciences. *Environmental Science & Policy* 10 (7-8): 668-684.

Kaunda, J. M. 2005. *Effective States and Engaged Societies: Capacity Development for Growth, Service Delivery, Empowerment and Security in Africa*. Gaborone: Botswana Institute for Development Policy Analysis, (BIDPA)

Kesby, M. 2005. Retheorizing empowerment-through-participation as a performance in space: Beyond tyranny to transformation. *Signs: Journal of Women in Culture and Society* 30 (4): 2037-2065.

Kolb, D. A., R. E. Boyatsis, and C. Mainemelis. 2000. Experiential Learning Theory: Previous Research and New Diections. In *Perpectives on cognitive, learning, and thinking styles*, ed. R. J. Sternberg and L. F. Zhang, eds, New Jersey: Lawrence Erlbaum.

MacLeavy, J. 2009. (Re) Analysing Community Empowerment: Rationalities and Technologies of Government in Bristol's New Deal for Communities. *Urban Studies* 46 (4): 849.

Mathers, J., J. Parry, and S. Jones. 2008. Exploring Resident (Non-) participation in the UK New Deal for Communities Regeneration Programme. *Urban Studies* 45 (3): 591.

Najam, A. 2005. Developing countries and global environmental governance: From contestation to participation to engagement. *International Environmental Agreements: Politics, Law and Economics* 5 (3): 303-321.

Nyerges, T., P. Jankowski, and C. Drew. 2002. Data-gathering strategies for social-behavioural research about participatory geographical information system use. *International Journal of Geographical Information Science* 16 (1): 1-22.

Oxenham, J., A. H. Diallo, A. R. Katahoire, A. Petkova-Mwangi, and O. Sall. 2002. Skills and Literacy Training for Better Livelihoods. *ADULT EDUCATION 58*: 8.

Peterson, N. A., and J. Hughey. 2004. Social cohesion and intrapersonal empowerment: gender as moderator. *Health Education Research* 19 (5): 533.

Pipek, V., O. Märker, C. Rinner, and B. Schmidt-Belz. 2000. Discussions and Decisions: Enabling Participation in Design in Geographical Communities. In *Community Informatics: Enabling Communities with Information and Communication Technologies.* , ed. M. Gurstein, 539-560. Hershey, U.S.A.: IDEA Publishing Group.

Rugg, R. D. 2001. A framework for the use of geographic information in participatory community planning and development. *Journal of the Urban and Regional Information Systems Association* 15 (2): 75-89.

Sieber, R., and C. Wellen. 2007. Blending Participatory GIS and Geo-Spatial Ontologies for Indigenous Knowledge Preservation.

Stephens, C. 2007. Participation in Different Fields of Practice. *Journal of health psychology* 12 (6): 949.

Uphoff, N. 2000. Understanding social capital: learning from the analysis and experience of participation. *Social capital: A multifaceted perspective*: 215-249.

Positional Accuracy Improvement : A Solution Using MapRite to Re-align Department of Planning's Datasets to the Western Australia's Spatial Cadastral Database

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ABSTRACT

The WA Department of Planning (DoP) is responsible for 11 custodial datasets. The geospatial positions of these datasets were originally derived by alignment to boundaries sourced from the State's Spatial Cadastral Database (SCDB). Because DoP datasets were created with no dynamic linkage to the SCBD, original correlations have been compromised over time due to spatial upgrades of SCDB. The resulting misalignments have limited DoP's full participation on the Shared Land Information Platform. To remedy this, a data quality improvement project was initiated to re-instate alignment and reduce associated risk. Solutions were researched and a methodology developed to meet DoP's unique requirements. An initial work package defined and documented data analysis and business rules for each dataset. Three potential software candidates were identified and evaluated against specific requirements and criteria. A proof of concept pilot study was initiated to evaluate the preferred supplier: Envitia's™ Positional Accuracy Improvement (PAI) software MapRite. Rigorous testing proved the capability to meet DoP's requirements; specifically, customisation for individual datasets using the configuration file, shift vector generation and intuitive built-in editor. Subsequently, the software was acquired so the project could proceed to full implementation. This involved using Maprite to re-align custodial datasets to 28th May 2010 SCDB and customising the configuration based on business rules. An average high confidence level of 80% was obtained on post processed datasets. The re-aligned datasets have provided users with a better product through the use of PAI software. This process initiated by DoP will ensure data integrity is managed and maintained.

1. INTRODUCTION

DoP custodial datasets are key products within the planning framework for Western Australia. The identification of planning features, such as zones and reservations, accurately in comparison to other land information datasets is a priority in order to enable the accurate and timely planning decisions. These datasets are not limited to internal users, but form an integral part of the planning process for the whole of Government, as well as private practitioners.

It has been identified that a form of Boundary Linkage - referential topology / positional improvement is required to guarantee spatially accurate data as based on the evolving SCDB supplied by Landgate.

DoP's custodial datasets, such as zoning and land use, are related in some way to the SCDB, either through coincidental survey boundaries or offsets to such boundaries through defined statutory distances. Over the years the relationship has been compromised due to spatial upgrades and Subdivision modifications of the SCDB.

This has been an ongoing problem for a number of years and there has been numerous attempts in trying to solve the problem which have proven unsuccessful to this point.

The inception of the Shared Land Information Platform (SLIP) in 2005? paved the way for the sharing of spatial information. Unfortunately, DoP's fundamental datasets were not suitable for the SLIP environment due to their spatial inaccuracy in relation to the current cadastre. For example, Region Scheme datasets have been captured in alignment with the cadastre at a fixed point in time and varies for each Region Scheme. All other custodial datasets are captured and updated with many varying cadastral date stamps which has resulted in the derived datasets not maintaining alignment with subsequent cadastral upgrades.

With the continual upgrade of the SCDB, DoP custodial datasets were getting more misaligned. Furthermore, there was more pressure from other agencies for DoP to participate in the SLIP environment and have DoP's custodial datasets to be placed on it. To overcome this major problem, the Boundary Linkage Project was initiated to address all issues and resolve them using existing off-the shelf software. Other drivers were the technology improvement over the years, which allowed for a higher rate of success comparing to previous attempts. The reputation and integrity of the Department to consider was also a major factor. With the custodial datasets placed on SLIP, it would show the variations and major misalignments of data against the latest cadastre. Furthermore, the misalignment resulted in poor GIS analysis returning incorrect calculations and inaccurate results.

2. PROJECT START-UP

In order for DoP to address the continual misalignment issues, the DoP has taken the lead in this area and the Boundary Linkage Project was initiated to solve the problems and ensure that continual alignment of custodial datasets are maintained against the latest version of the cadastre.

The high importance of this issue, not only for DoP but also for a number of agencies, resulted in the formation of the Positional Accuracy Improvement Group (PAIG), through the Western Australia Land Information System (WALIS). This group is comprised of members from various State Government agencies and was formed to address and resolve these issues through a whole of Government approach.

2.1.Objectives

The prime goal of the Boundary Linkage - Spatial Upgrade project is to achieve spatially upgraded custodial datasets that allow for more accurate and GIS analysis and enquiry, with more confident results. Custodial datasets are to be aligned for suitability on the SLIP platform. Data management practices are to be formulated that allow for custodial datasets to be managed against the State's Cadastre. The main objectives are:

1. Assess and consolidate all custodial datasets in alignment with the latest spatially upgraded cadastre
2. Implement a data management process that maintains this alignment with the cadastre on an ongoing basis
3. DoP's fundamental zoning/land-use datasets will be aligned with the spatial position of the Landgate Cadastral Land Boundaries as at 28 May 2010
4. DoP's datasets will be spatially upgraded and suitable for WA's Shared Land Information Platform (SLIP)
5. Datasets can be interrogated using GIS analysis techniques to achieve results with a high degree of accuracy and confidence, in a more timely manner

2.2.Stages

The approach taken for the Boundary Linkage Project was a four stage process.

The four stage process are:

- 1st – Project Initiation
- 2nd – Test case and assessment of data consolidation process
- 3rd – Dataset processing
- 4th – Implementation of data management process

See Table 1 for a more detailed stage outline.

Stage	Description
Stage 1 - Initialisation Stage	- In house assessment of custodial datasets - Boundary upgrade status so far undertaken by internal users of custodial data. - Research to be carried out on Spatial upgrade process undertaken by external agencies. Consultation to be carried out with external stakeholders to assess the approach of other agencies and government enterprises. - Research and submission to be provided to Landgate to progress Spatial upgrade program for areas of importance for custodial data. - Research into data management process to be implemented in order to formulate process to be carried out on upgraded datasets. - It has been noted that the supply of incremental data information for the SCDB will increase accuracy of conversion in the software application.
Stage 2 - Test Case process	- External Software supply and response to DoP's project requirements. - Test case undertaken with software supplied by external consultant. Contractor to carry out test case spatial upgrade of data based on a base lined Landgate cadastre and the Greater Bunbury Region Scheme (GBRS) - Internal review to be carried out on Landgate supplied SCDB. Incremental update to be investigated and data management process to be formulated for updating custodial data. Change vector generation and application to custodial data. - Test case data analyzed at a quantified accuracy level based on agreed standards between Software vendor and DoP. (0.01m) - Data management update Test Case. Process to be carried out against test case data supplied by software consultant. - Incremental update of cadastre – based on quarterly update to be applied to dataset as an ongoing management process.
Stage 3 – Dataset processing	- DoP custodial data is processed by software application and verified for accuracy. - Re-supplied data is incorporated into existing corporate database - Data management and update plan implemented on a scheduled update process or as notified by Landgate of substantial changes in the upgrade of the SCDB
Stage 4 - Boundary Linkage Implementation	- Implementation of internal data management plan into production system. Program initiated to maintain data against updated SLIP SCDB

Table 1: Detailed Stage Plan

3. PILOT TESTING

After the initial stage to identify requirements, define the data management processes and review the software, the next major stage was to put out a tender (request for quote) and select a successful supplier for the project. To ensure that the supplier could meet a certain set of requirements, a scoping analysis was undertaken and an acceptance criteria was developed to assess each software applicant based on the criteria. See Table 2 for the acceptance criteria listing.

Three suppliers submitted for the tender and they were Envitia, One Spatial and Spatial Tapestry. The successful supplier was chosen based on the applicant addressing the requirements outlined in the request for quote. As part of the request for quote, the successful supplier will be required to demonstrate that the software will be able to meet the minimum acceptance criteria, a Pilot testing stage is required before awarding the full contract. If this proved successful, then the project will continue and go through implementation.

Specifications	**Minimum Acceptance Criteria**
Spatial Shift Specifications	Feature boundaries have to maintain coincident boundary alignment with cadastre line
	Feature geometry to be maintained (shape and area)
	Feature offsets to be maintained based on cadastre offsets
Processing	Batch processing required.
	Cadastre shift vectors to be generated.
	Shift vector accuracy reporting
	Shift processing results reported.
	Shift errors to be reported. Areas that do not meet transformation requirements to be identified for manual processing and QA.
Timings	Overnight processing of data is to be expected. Region scheme (Metropolitan) contains 1857 polygons in three feature classes. Based on a 4 second polygon processing time, it is expected that a Region scheme can be processed in ~2-3 hours.
	Processing time of a region scheme is expected to be done in an overnight process. Results to be verified by officer the following day. Manual verification and correction to be carried out based on a 90% success rate in spatial upgrade
Training/Support	Training in Software setup and configuration to be supplied by software provider.
	Data configuration and business rule setup training to be carried out based on DPI specific datasets.
	System support provision to be provided based on software maintenance provision.
Business rule customisation	Software configuration to allow for customisation of processing to reflect individual dataset requirements
Data Management process	Data management interface where processed data can be interrogated and corrected based on dataset business rules defined.
	GUI provision for user verification and data management stage

	Tool provision for identifying spatial shift errors with the custodial data
	Tools for correcting errors
System Specifications	PC/server based software processing to conform with DPI specifications and setup.

Table 2: Acceptance Criteria Specifications

The successful supplier chosen was Envitia™ with their software (Maprite) evaluated based on the functionality and processing capabilities. The pilot study was carried out on the Greater Bunbury Region Scheme (GBRS) Zones and Reserves dataset, which requires spatial alignment with the (SCDB). The evaluation also determined whether the configuration settings, business rules and pre-determined processes and procedures put into place have the capacity to process the required custodial datasets.

Two separate phases of processing were undertaken. During the first processing phase, the Zones and Reserves dataset was divided into subtypes (21) and processed accordingly. Summary statistics specified an 88.2% high, 7.1% medium and 4.7% low confidence levels for the Zones and Reserves Dataset. Post processing analysis and QA of phase one indicated slivers and holes were present within the processed data and it was determined that the processing method was too labour intensive and could not be applied to remaining custodial datasets within a realistic timeframe.

Second phase processing was initiated in order resolve those highlighted in phase one. This method adopted a more direct model for processing whereby the dataset was divided into three. The Waterways and Regional Open Space zones were assigned individual configuration files due to their lack of coincidence with the cadastre. The remaining Zones and Reserves were processed separately. Results specified 95% high, 1.5% medium and 3.5% low confidence levels. A significant increase in overall accuracy was noted along with a major reduction in processing time and manual editing. It has been accepted that a specific amount of manual editing will have to be performed in the post PAI phase. This is understandable, as some processing issues have been directly attributed to inherent inaccuracies within the GBRS dataset and lack of associated baseline data.

In summary, the GBRS Pilot has indicated that the MapRite software meets the specifications required for the PAI of the DoP's custodial datasets. The software has performed the required spatial shift of the GBRS Zones and Reserves data and demonstrated its capability in the processing of large datasets. The MapRite software also provides an easy to use graphical user interface, optimal QA tools and high quality standard data management capabilities that meet all system specifications within the DoP. Therefore it was recommended that the software be purchased in order to fulfill the required upgrade to the Department's custodial datasets.

3.1.Maprite Overview

MapRite uses a rule-driven algorithm to determine the most appropriate solution between the "old" data (baseline cadastre) and "new" data (current cadastre). By comparing the new and old situations, MapRite is then able to derive a set of confidence factors that provide an accurate indication of the success of the processing.

The software also tailors for individual dataset business rule customisation in which rules are incorporated into a "configuration file" and various parameters are assigned for data processing.

Once processing is complete, a "traffic light" flagging system highlights polygons/objects in relation to their associated confidence factor. This inbuilt "flagging" system categorises results into High (Green), Medium (Amber) and Low (Red) confidence levels which assists in quick Quality Assurance (QA) and potential manual data intervention. The software also has split screen capability for easy comparison of pre vs post PAI data and an inbuilt editor whereby modifications\edits can be easily accomplished.

The software also provides an easy to use graphical user interface, optimal QA tools and high quality standard data management capabilities that meet all system specifications within the DoP.

4. IMPLEMENTATION

After successful pilot testing using Maprite, the contract was awarded and moved onto the next stage. This stage was to spatially upgrade all of DoP's custodial datasets using the Maprite software. The datasets to be processed are:

- Clause 21 , 27 & 32 Areas
- Bush Forever 2009
- Heritage Council Sites WA
- District & Local Structure Plan Index
- Improvement Plan Areas
- Metropolitan Region Scheme
- Peel Region Scheme
- Greater Bunbury Region Scheme
- Planning Control Areas
- Redevelopment Act and Scheme Areas

4.1.Dataset Processing

Processing of each custodial dataset consisted of three main phases. They are Pre-processing, Core processing and Post processing. In order, for each dataset to be processed, Maprite uses a Project setup for processing each individual dataset. The Project can be configured according to the business rules of each dataset and their unique situations. The steps are further described in the following sections.

4.2.1.Pre Processing

Before any processing is done, the misaligned custodial datasets needs to be identified and a dataset analysis is perfomed. It is to identify any odd situations within the dataset that might be problematic during the processing phase and resulting in inaccurate results. Business rules for the dataset is then configured and takes into account the odd (or problems areas) situations. This can include questions such as, What is the baseline data that the custodial dataset is referenced to? e.g. Cadastre, Local Government Authority. Other questions include, is the baseline data available and what is the accuracy, currency and format. Also, important is the difference (shifts) between the old and new cadastre. These are all important questions and are answered or identified before any processing is done. It will result in having a high percentage of polygons falling in the high confidence level.

The next step is to prepare the dataset for processing. This involves converting each dataset to Shapefile format (one of the formats Maprite supports). Ensure the cadastre is clipped to current extent of dataset, as this will save time in processing.

At this point, the dataset can be further extracted or split up to many datasets. This can be due to the initial investigations where some areas or for instance the Region Scheme zones behave differently to each other. This will require a customised configuration file and processed each separate zoning separately.

To begin processing, a Project needs to be set up in Maprite. The components are Old Map (baseline cadastre), New Map (current cadastre), Link Data (shift vectors), Input Datasets (e.g. MRS) and Project Configuration (customised configuration file).

At this stage, the configuration file is customised before the Core processing is performed. The detailed analysis and business rules prepared earlier will be incorporated into the configuration file. This can include setting tolerances for points that are considered to be near enough to be coincident or the angles at which points are coincident.

Shift vectors are generated using the Link Generation. These are the differences between the baseline and current cadastre.

4.2.2.Core Processing

The core processing is when the actual software will run and spatially upgrade the custodial dataset according to the Project setup.

This occurs in three steps as outlined below.

- Step 1; this step essentially analyses your data, recording the relationship between it and the old map and also relationships between entities in the input datasets.
- Step 2; this step reconstructs your data against the new map, using the information gathered in the pre-processing step.
- Step 3; the final step calculates metrics and makes any final checks to ensure the data is optimally positioned.

4.2.3.Post Processing

When the processing has finished, a visual entity quality assurance (QA) is done on the processed dataset. This is to ensure that the processed dataset has been shifted properly.

This task is made easier due to Maprite's Traffic Light Flagging System. This traffic system identifies the confidence level of each polygon. There is also a display of the confidence metrics for each individual polygon entity that shows the weighted confidence and confidence multipliers as specified for each configuration file.

Using the confidence levels, the next step is to QA and make edits to each polygon if required. Maprite has a very easy to use editor, line trace, able to delete and insert vertices to make changes to each individual polygon. The results summary provides a quick overview of all features in a readable table view. User comments can also be made into this table.

4.3.Current Status

Currently, seven custodial datasets have been spatially upgraded to align with the 28th May 2010 cadastre. The remaining datasets will be processed over the next month. The spatially upgraded datasets will be placed on SLIP progressively towards the end of the project and this will be made available to the public.

4.4.Issues

There has been a number of issues that were unforeseen and had to be dealt with during the project. Some of these issues have been resolved while others are still being dealt with. The list of these issues (and brief summary) are below.

- Dimension files for Region Schemes – the arrowheads were captured as lines and caused problems with processing. This also include the lines not connected to the arrowhead.
- Region Scheme datasets – they are statutory documents that are legally binding and any realignments made to them needs to be within the Planning and Development Act.
- Complexities of the Metropolitan Region Scheme – the complexity of this dataset created some issues with processing time and performance. These were addressed with an update of the software.

4.5.Next Steps

After completion of this Project, the DoP will be putting in place a program to maintain the update of each individual custodial dataset to align with the current cadastre. At this stage, a timeframe has not been set as to how often the custodial datasets will be realigned. This will depend on a number of factors, such as the time taken for each update and resources available.

The update strategy will eventually include the Local Planning Schemes, which are currently being realigned as part of another project.

5. CONCLUSION

The Boundary Linkage Project was initiated to solve an ever increasing problem for DoP. Many attempts were made to realign or spatially shift DoP's custodial dataset to the current cadastre. The advances in technology and other factors has led DoP to obtain the services of Envitia, using their PAI software Maprite to solve the misalignment.

The Maprite software was put through rigorous testing using the GBRS dataset as a Pilot Test. This proved successful with high confidence levels of more than 80%. Implementation to spatially shift the remaining custodial datasets were put in place using a data management plan. Each individual custodial dataset were processed separately using customised configuration files which resulted in obtaining high confidence levels of at least 80%.

Overall, the Maprite software has delivered the solution that was required by the DoP and the resulting datasets will be placed on SLIP, making it available to the Public. A program will be put in place to spatially update the custodial datasets on a regular basis.

Title: Total Resource Management

Subtitle: *Crossing lines between natural resources and agricultural production*

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Speakers Bio

Kathe moved into the field of Natural Resource Management several years ago after many years experience farming, auditing and participating in the organic industry. Her main work and study in the past five years has been in Environmental Management Systems and organic management systems. Her work has taken her across Australia and throughout the Asia Pacific region. Kathe works with farmers and other landholder's to manage and improve their natural resources and on-farm practices, noting in that time the synergies and the benefits of integrated management.
This presentation was undertaken as part of Kathe's work with the Blackwood Basin Group.

The Blackwood Basin Group (BBG) is a not-for- profit organisation dedicated to the health and future of the Blackwood Catchment. The Blackwood Catchment covers approximately 22,000 square kilometres. The BBG has a 20 year plus history of successful project management for catchment scale, community and landholder initiatives. The organisation also participates in political and social discussion, and community training

Introduction/Summary

This presentation highlights the increasingly blurred line between agricultural production and natural resource management. Farmers are increasingly noting the benefits of managing the total property, rather than just the production areas, for maximum production outcomes, aesthetics and increased biodiversity.
Workers in the Natural Resource Management sector increasingly understand the importance of working with farmers and other landholders to improve the total environment to the benefit or our natural resources.

The "fence to fence" agricultural production approach has left some lasting negative impacts in the form of soil degradation, wind and water erosion, animal and plant species decline and lower agricultural production outcomes. The Blackwood Basin Group works to improve the understanding and ability of land managers to integrate their total property and surrounding landscape into a sustainable system that can support both farming and the natural system.

This presentation will demonstrate the benefits of integrated managed to both production outcomes and the natural resources. After some discussion notes on the benefits of such management three case studies will be presented. These case studies highlight a range of agricultural operations where production and natural resource management coexist for improved production outcomes and to the benefit of the environment on and around each property.

Agricultural production and natural systems, cooperation or competition?

There are differences in the way these agricultural systems and natural systems operate but also the potential for interaction between the two systems. For example a lot of the conventional inputs used in agricultural production are harmful to the natural environment if they leach or blow from the area they are applied.
If the use of these applications is targeted and held in place to be taken up by the plants they were intended for, the surrounding bush can thrive and provide benefits such as shelter and shade, habitat for beneficial species, animal food in an adverse season and materials for improving the infrastructure of the agricultural system.

The key to this interaction is good stewardship and holistic land management.

If the agricultural system is not well managed it can impact negatively on the total system by degrading soil, water, and biodiversity and/or air quality. New pests and diseases can be introduced to the total system. Agricultural inputs can blow off, run off, leach or seep causing pollution and erosion. Overgrazing can also cause erosion and pollute the natural system with an overload of nutrient.

If the natural system is not well managed it can host feral species such as dogs, foxes rabbits, camels, pigs, donkeys, deer, fish and invasive species of fungi and insect pests. In extreme weather conditions the natural system can promote negative impacts through fire, flood, and storm.

However with holistic management a farming system can provide a positive increase in species diversity and an increased land management capability for the total environmental system.

Planning

The key to successfully integrating the demands of the natural environment and agricultural production is forward planning. Over the years this need to plan ahead is increasingly becoming acknowledged by farmers, support workers, agricultural consultants and of course, insurance agents.

Whether the title of this planning process is EMS (Environmental Management Planning) PMS (Property Management Planning) or any of the plethora of titled planning systems being promoted currently the concept is sound.

Plan before acting, implement the plan, check that the plan is working and make the changes necessary to maintain or improve the outcomes of the plan. Budgeting is essential to this approach.

Following are three examples where forward planning has been used to implement best practice in integrated farming and natural resource management.

Case Study 1

The Blackwood Basin Group is working with a group of broadacre farmers located around Katanning, to roll out on-farm trials to provide examples of ways to improve soil health to minimise wind erosion, increase water holding capacity and improve yields without negative impacts to natural bush and water resources.

The trials are funded and overseen by the South West Catchment Council with input and consultation by independent agronomists.

In the first instance a plan was developed by the farmers in conjunction with independent agronomists as to the best locations, volumes and application method for the trial. Strategies were outlined and confirmed in a group workshop prior to the break of season.

The trials consists of replacing conventional fertilisers with a pelletised compost product that is applied at the time of seeding through the same equipment as the seed (airseeders).

The aim is to provide some short term fertility benefits but also to input organic matter to benefit the soil and increase its holding capacity and general health over a number of years. This approach has the benefit of utilising a fertility product with less potential for a negative impact on the native plant species and waterways, and a greater potential of holding in soil and input product in place rather than leaching or blowing in adverse weather conditions.

The four farming families engaged in the trials were partly selected because of their history of good land management practices. In all cases the farmers are managing their production areas with consideration given to their surrounding environment, with native buffers or even alleys of native trees throughout the paddocks.

Sampling has been done to benchmark each production system so the success of the trials can be measured.

Case Study 2
Bee Winfield and Stewart Seesink are a small landholder couple who are making an income through integrated animal and crop management. They manage vulnerable wetland areas and prevent negative impacts from the production areas as part of the total property management.

Merri Bee Organic farm is a 27 acre property on the Blackwood River near Nannup. This is a commercial integrated production operation working with an organic certification and a large diversity of crops and animals. A wetland of approximately 7 acres is situated in the middle and to the north of the property, adjacent to the river. This swamp area is surrounded by steep (60%) slopes.

Bee and Stewart have vastly increased their native and commercial vegetation from “a handful of trees” on their arrival in 1985. Four out of eight steep slopes have been revegetated with trees, and wattles, tea tree, sedges and rushes are regenerating in the swamp area. A wide range of frogs, reptiles, wild birds, small mammals and macro invertebrates are a welcome addition to their landscape although Bee does note that the Quenda is a bit of a nuisance in the vegetable garden.

Bee says “We are able to make a living farming and simultaneously let wilderness creep back on our land.”

Recently Stewart and Bee made a review of their progress, attending a planning workshop aimed at maintenance and restoration of fish habitat. As a result of this planning exercise they have applied for and received funding for the latest stage in the development of their property.

Sheep and cattle have been fenced out of the remaining sensitive areas (steep slope and wetland) with fencing completed and planting due as soon as they get a decent rain. The revegetation sites will provide a filter between production activities and the river, enhance the aesthetics of the property, provide cut feed for the farm animals, mulch for the compost and increase habitat for the native species present in the area.

Case study 3
Boathaugh Estates is located in the lower southwest of Western Australia. The property is situated on the Blackwood River near Alexandra Bridge, Karridale. The property has approximately 10km of Blackwood River frontage.

This is a corporate farm managed by Jill and Colin McGregor as a large scale beef cattle operation. The Managers manage the property for an economic return but do not neglect their riparian and other bush areas. This operation has achieved a balance between commercial farming and healthy areas of natural bush and riparian areas on property, with a positive impact on the total river system running through the property. This is all carefully planned and monitored as part of ongoing property management, budgeted and implemented in manageable steps over a number of stages and years.

A dam has been built along the ‘Rushy Creek’, one of the tributaries to the Blackwood River that runs through the property. To offset the negative impact to native fish species a bypass channel was built to enable the upstream and downstream movement of fish species to and from the Blackwood River. The channel is 1km in length and is very important in connecting the upstream and downstream sections of Rushy Creek along with the fishway into the dam itself during high flows.

The Centre for Fish and Fisheries Research (Murdoch University) and the Department of Water have undertaken some sampling between August and October 2010. The sampling occurred monthly and involved examining both upstream and downstream movement of fish and crayfish in Rushy Creek both below the dam and in the stream upstream of the dam where the bypass channel exits.

Both fishways enabled the passage of native fishes. Species present were the Western Minnow, Western Pygmy Perch and most importantly limited numbers of the threatened Western Mud Minnow.

In addition to the three native fishes a fourth freshwater species the Nightfish *Bostockia porosa* and a native estuarine species the Swan River Goby were also recorded. Freshwater crayfishes the Marron *Cherax cainii* and Gilgie *Cherax quinquecarinatus* were also present along with a number of native frog species.

Boathaugh is now establishing a riparian vegetation zone along the length of the bypass channel (approx 1km) to a width of 2 metres. This zone will include fringing and lower bank varieties along with larger varieties to the outer area of the zone. The zone has already been completely fenced off to minimise stock access.

A benefit of this revegetation is the extra potential for shading (and cooling) the waterway in the increasingly warm summer temperatures. The extra vegetation makes a good buffer and shelter for the cattle in adverse weather conditions and could provide a feed source in a dry summer.

Summary

The lessons learned from these operations and others like them include the financial, aesthetic and long term benefits to agricultural production areas from healthy bush and riverine systems. The ability to manage both the agricultural and natural system to improve the total system has brought the above benefits in every example highlighted in this presentation.

The managers of Boathaugh can invest in a healthy riverine system as part of their overall management of the property and that investment will provide returns for the agricultural system and the wider environment.

Bee Winfield and Stewart Seesink can profitably farm their land without impacting negatively on the farmland or the surrounding environment. Over a number of years they have improved the total property for aesthetic and economic values.

The Katanning farmers understand the benefits of improved land management and utilise funding opportunities to expand their farming options while improving the environment they farm in. They have taken a risk in one of a series of adverse years to experiment with new farming methods that have the potential to improve soil structure and by improving that making the environment they farm in more sustainable.

In times of increasingly unpredicatable weather patterns and changing regional climatic trends these positive actions towards a sustainable future are commendable and are examples that should be promoted and an expanded upon.

References

Blackwood Basin Group www.blackwoodbasingroup.com.au

BestFarms www.bestfarms.com.au

Custom Composts www.customcompost.com.au

SWCC (SouthWest Catchments Council) – www.southwestcatchmentscouncil.com

Merribee Organic farm www.merribeeorganicfarm.net.au

Boathaugh Estate www.**truelocal.com.au**/business/**boathaugh**-w-a/karridale

Centre for Fish Studies, Murdoch university WA www.**cffr.murdoch.edu.au**

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

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IMAGE RECONSTRUCTION IN THE CONTOUR DOMAIN

ABSTRACT

Digital image enhancement systems are essentially pixel-based. In this paper, a novel method of multi-frame image enhancement employs contours rather than pixels as the primitive working unit. The feasibility of this proposal is based on the fact that gray-scale images can be sufficiently and accurately represented by their contour maps if a suitable contour model and scale selection method is used [5].

In this process several low-resolution shifted frames of the same scene are (a) registered (b) transformed into their contour domain, and (c) grouped or mapped globally within a singular framework to create an enhanced contour composite. Inverting this improved contour representation yields a high-fidelity reconstruction of an image in pixel format with more details than any of the original input frames.

The mapping of the low-resolution contour images within a singular framework takes advantage of the differences (or shifts) existing between their contour representations. These shifts are computed using an innovative image registration technique that can achieve accuracies of up to 0.01 of a pixel. The technique is based on DCT (Discrete Fourier Transforms) and normalized cross-correlation.

Controlled tests show that this global contour mapping approach, with subsequent converting to a compact and improved raster image, provides for an efficient and simplified method for multi-frame image enhancement. As compared to pixel-based multi-frame image enhancement processes, the proposed method may be computationally more efficient as it allows the detection, filtering and elimination of redundant contour data which may have little or no effect in the final enhancement.

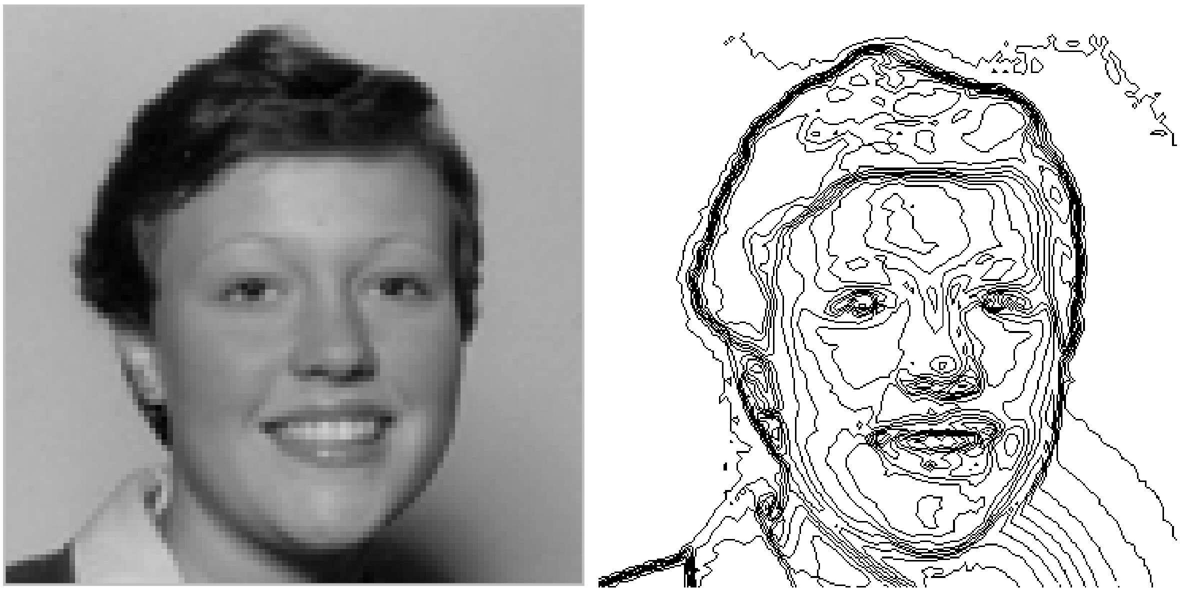
Although still in the experimental stage and restricted to gray-scale images, the proposed method is particularly viable in applications involving facial enhancements of compressed video frames.

1. INTRODUCTION

A digital image is a discrete approximation of an image obtained by sampling points with discrete coordinates and quantizing the values of each sample. It is generally formed by a finite number of sample elements equally spaced over a square grid with a rectangular shape [4].

Each element is called a pixel and has an intensity value. The rows and columns of elements determine the spatial coordinates of the pixel; and the intensity determines its gray-scale value. In a gray-scale image, all pixels have shades of ranging from black to white. In the case of colour images, the intensity determines the colour of each pixel according to some colour model, such as RGB (Red, Green and Blue).

Hence, as shown in Figure 1(b), a digital image can be represented as a three-dimensional surface or by using contours where each point (i.e. a vertex) of a given contour corresponds to a position (x,y) having a constant gray-scale intensity or elevation z, respectively. The definition of contour used in this work relates to the term used in cartography and surveying where a contour line joins points of equal elevation (height) above a given reference level. Note that this definition may differ from the one commonly used in image processing where contours relate to shapes, edges or to lines and object boundaries.



(a) (b)

Figure 1 : An image (100^2) of the face (a), and a contour representation (b) using contour increments of 10 gray-scale intensity values on a scale 0-255.

In the general process of recording an image, there is a natural loss of spatial resolution caused by the non-zero physical dimension of the individual sensor elements, the non-zero aperture time, optical blurring, noise and motion [13]. However, this loss of spatial resolution may be largely reduced by combining a number of images of the same scene via pixel-based methods of multi-frame image enhancement [6] [11]..

This is the particular case of video images where multiple images of the same scene taken in rapid succession can be extracted from the footage. Video sequences usually contain a large overlap between successive frames and regions in the scene are sampled in several images at different sub-pixel positions. This multiple sampling can often be combined to achieve images with a higher spatial resolution.

Differently from pixel-based multi-frame image enhancement methods, the approach here is to use contours as the primitive working unit. In this context, Figure 2 shows two slightly shifted contour representation of the face in Figure 1(a). Although the two images represent the same object they display a number of differences. For the same number of contour increments, contours lines in one image have disappeared while new contours have emerged in the other.

Hence, a composite image can be constructed by combining the contour representations of a sequence of images of the same object within a single reference framework. The result of this process will include more contour lines (hence information) than any of the initial input frames. Once a composite contour map is attained a reverse process is applied to transform this composite into a raster format (pixels).

In summary the proposed image enhancement method involves the following steps:

1. *Image registration*: Estimation of sub-pixel shifts among the different low-resolution input images depicting the same scene.

2. *Contour detection*: Each low-resolution frame of the sequence is converted to a contour format. The contour increments will depend, in general, on the images' dynamic range (largest and smallest possible values of pixel intensities within the input frames).

3. *Contour grouping*: The contour lines extracted from the input images are merged and/or mapped within a common reference frame using the shifts computed in step 1.

4. *Image reconstruction:* The combination of data is then filtered so that redundant contours are eliminated from the process of reconstructing an enhanced image in raster format for final display, analysis and use.

This succession of steps were automated and assembled with a package of basic image processing functions and tools included in Matlab 7.1 (www.mathworks.com, 2005).

Figure 2 : Two contour representations of the same scene sampled at different sub-pixel positions. For the same number of contour intervals, the differences between the two frames are evident.

2. CONTOUR DETECTION

The process of generating contours comprises the step of assigning coordinate values to pixels in the raster format image data and interpolating between pixels to find the coordinates of points in the path of a contour having a gray-scale intensity value.

Each pixel can be assigned x and y coordinates, which may conveniently be based on the coordinates of the centre of each pixel. Each pixel then has at least a pair of coordinates and a pixel gray-scale or intensity value. If two adjacent pixels have gray-scale values of 40 and 50 respectively, then a contour for gray-scale value 45 may lie between these two pixel centres. The coordinates in pixel space of a point on this contour can be estimated by interpolation, thus enabling the contours and/or the contour bounds to be estimated to sub-pixel accuracy.

For the class of facial images investigated in this work, the contour interval or increments were selected based on the dynamic range and/or on image histograms. Image histograms provide a convenient, easy-to-read representation of the concentration of pixels versus pixel brightness in an image. Using this graph it is possible to discern how much of the available dynamic range is used by an image [7].

The dynamic range is represented by how many levels in the scale are occupied. For instance, a group of pixels falling between values 25 an 210 (within a range of 0 to 255, see Figure 3), with none in the other regions, indicates a relatively wide dynamic range of brightness thus, in general, requiring a larger contour representation than an image with a narrow scale distributions (small dynamic range).

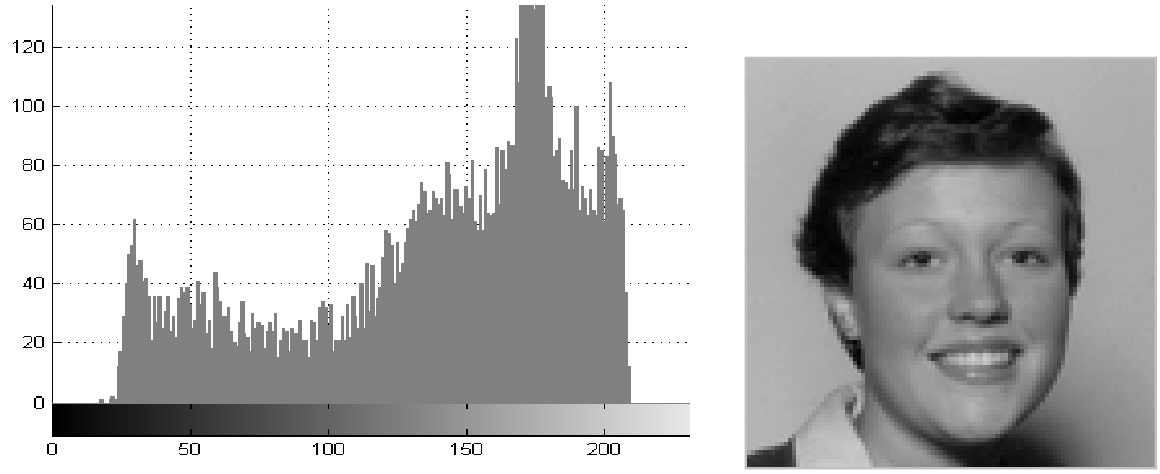


Figure 3: The histogram on the left shows the distribution of pixel intensity values for the image displayed on the right.

Figure 4 illustrates a series of contour lines as produced from an array (4x4) of uniformly spaced pixel intensity values. In this instance the contours increment was 4 units. The dots connecting the contour segments are referred to as vertices. There exist a number of methods and computer packages used for constructing contour lines from equally distributed data points [1]. The contours in Figure 4 were derived by interpolation using a weighted average.

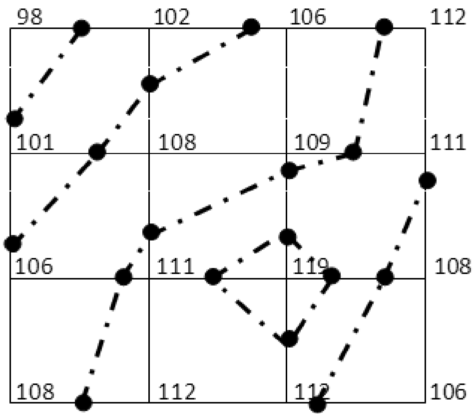


Figure 4 : Contour representation (with contour increments of 4 units) of an array of 16 uniformly spaced pixel brightness values

A number of tests by the author have shown that contour increments of 5 gray-scale units may be sufficient to reconstruct images of faces with relatively large dynamic range. This was confirmed by way of comparing the results of reconstructing a set of facial images from their contour representations to their original raster format. These tests were carried out using three common interpolators, that is, Weighted Average (WA), Bilinear and Bi-cubic [9]

The graph in Figure 5 is typical of the degree of accuracy to be expected when reproducing a raster image from its contour representation. The graph is based on the image of the face in Figure 1. The r.m.s. (root mean square) relates to the differences between the original image of the face and the same images reconstructed using the vertices of the contours for increments ranging between 1 and 10.

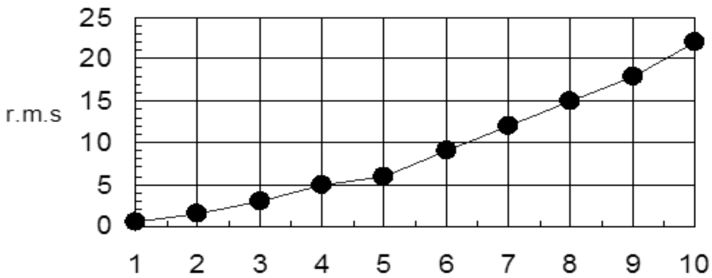


Figure 5 : The graph shows the r.m.s. of the differences between the original image of the face in Figure 1 and the same image reconstructed using contour lines with increments ranging between 1 and 10.

The graph shows an exponential degradation of the r.m.s. value as the contour interval is increased. The reverse interpolation method used in this example was Weighted Average [1]. In all cases, the number of vertices required to reconstruct the original image of the face was less than the total number of pixels of the image itself (100^2). By way of comparison, the .txt file needed to store the vertices required to reproduce the face (for contour increments of 5 units) used approximately the same amount of memory (i.e. 10KB) of a JPEG compressed version of the original image (i.e. 10KB), while reproducing a more accurate image with more visual details.

3. SUB-PIXEL IMAGE REGISTRATION

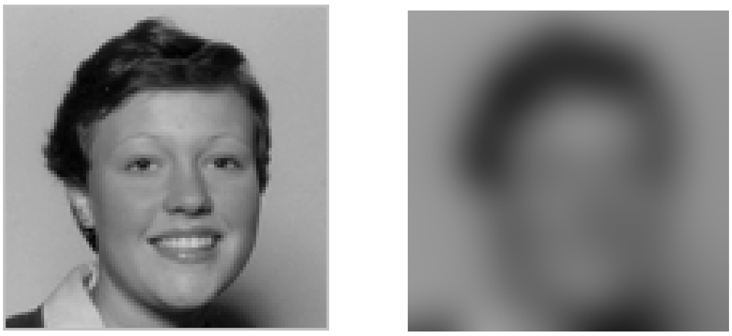
There exists a number of methods for determining sub-pixel translation parameters (i.e. in x and y) existing between two shifted images depicting the same scene. The method used here was devised by [8] and is based on DCT (Discrete Fourier Transforms) and normalized cross-correlation registration techniques [14].

The technique allows images to be registered or matched without using control points in the registration procedure. The accuracy of the registration is user selectable and can achieve accuracies of up to 0.01 of a pixel. For two given images *F* and *G* the registration outputs the normalized root-mean-squared error (n.r.m.s.e.) between *F* and *G*, their global phase angle and the row (x) and column (y) shifts between the two images respectively.

For a more accurate detection of the shifts or offsets between two images, the image must contain some features that make it possible to match two under-sampled images. Very sharp edges and small details are most affected by aliasing, so they are not reliable to be used to estimate these shifts. Uniform areas are ineffective, since they are translation invariant. The best features are slow transitions between two areas of gray values.

These areas are generally unaffected by aliasing and such portions of an image need not to be detected specifically, although their presence is very important for an accurate result. In this context, before a given sequence of images of the same scene is registered, a low-pass filter may be applied uniformly to each image. The purpose of a low-pass filter, as shown in Figure 6, is to smooth (1) sharp edges and small details, (2) sudden changes of intensity values, and (3) the distortions created by a compression process.

The motion estimator (registration procedure) adopted in this research determines the x and y shifts between any two images, but what is really required is the relative positions of a sequence of images. By calculating the shifts with respect to a single reference image, only one realization of the relative positions is obtained. By repeating the procedure for another reference image, a second estimate for the relative positions is made.



(a) (b)

Figure 6: The original unfiltered image of the face (a) and (b) after applying a low-pass filter (Gaussian, 18 pixels radius).

Reiterating this process for all images in the sequence, a better estimate of the relative shifts, image to image, can be found. The statistical measure used to determine the 'best' possible value for all possible combinations of the motion vectors between a set of shifted low-resolution images is the vector median. If the vector mean was taken instead of the median, then the final motion vector would be an entirely new vector, and not one of the vectors originally estimated. In addition, the mean is less robust than the median if outliers are present [10].

4. IMAGE RECONSTRUCTION - FROM CONTOURS TO PIXELS

Upon determining the shifts between the images, the vertices of the contours are projected or mapped on a uniformly spaced high-resolution grid (see Figure 7). Depending on the final resolution required, this grid may be selected so as to create more pixels in x and y than any of the original input images.

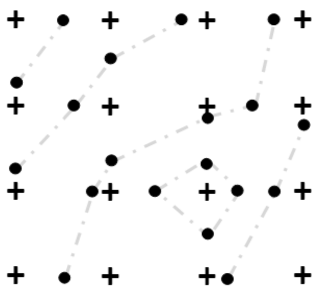


Figure 7: Contour vertices (dots) are used as the randomly spaced contour locations needed to determine the pixel values which would exist at the intersections of a regular grid (crosses).

Only those contours that provide additional and/or relevant information are used in the process. This is important because the input images may contain multiple redundant contours (i.e. intersecting or nested contours), any of which might logically be used as a basis for discrimination or, on the other hand, used in the reconstruction of an improved image composite. In other words, contours may be filtered so as to eliminate those contours which may have a small or no contribution in the accuracy of the final reconstruction, thus saving substantial processing time.

A potential test for whether a contour is a candidate for removal is to compare the centroid values, the area these contours occupy and the shorter and longest distance to the centroids [12]. These parameters may offer the best statistical constraint for deciding whether a contour is very similar to another and thereby could be removed.

Also, within any group of at least three close nested contours it may possible to test for redundant contours by removing the middle contour and interpolate and/or diffuse between the other two. However, this process may have the disadvantage of smoothing and/or distorting particular high frequency (sudden changes of brightness values within an image) information necessary for a more accurate reconstruction of the enhanced composite.

As illustrated in Figure 8, string filters may also used to remove vertices from contours. Using a user defined tolerance, string vertices that are within an offset tolerance of straight lines are removed. That is, a string filter removes vertices from contour lines that do not deviate by more than a specified offset tolerance from straight lines joining successive string vertices. Optional filtering techniques may be considered, alone or in combination. For instance, adjacent string vertices may be removed if they are equal to a given tolerance either in plan position only (i.e. have similar x and y co-ordinates), or equal to a given tolerance for x, y and z co-ordinates (where z is considered as the pixel intensity value).

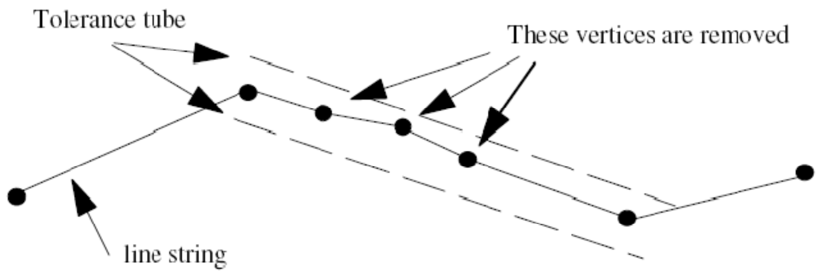


Figure 8: A string filter option is used to remove surplus vertices from contours lines.

To determine the pixel brightness which would exist at the intersections of a regular grid using randomly spaced contour vertices locations, several interpolators may be used depending on the application and accuracy requirements. One of the methods for interpolating scattered data to a uniform refined grid is referred to as Kriging. This geo-statistical method was used because it is a statistical interpolation technique that considers both the distance and the degree of variation between known data points when estimating values in unknown areas.

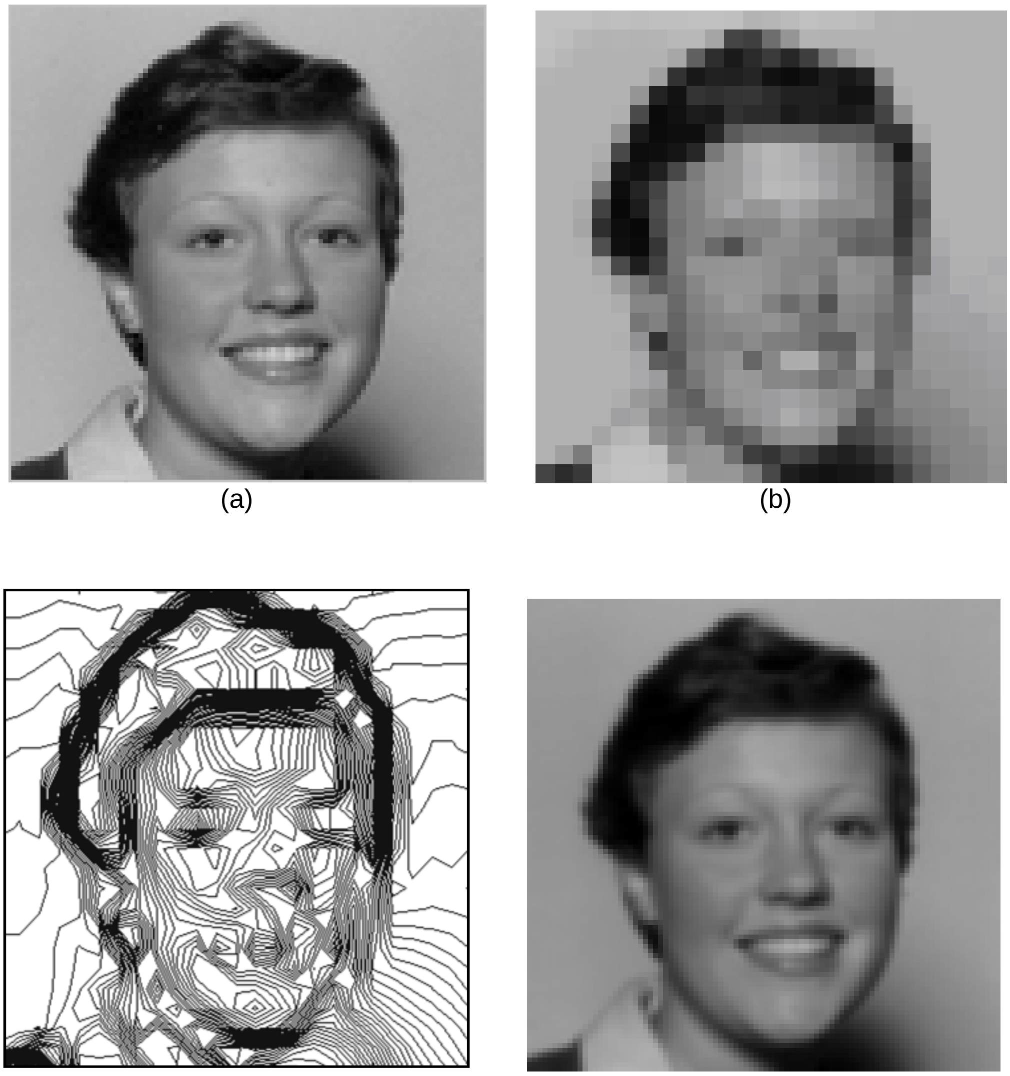
A kriged estimate is a weighted linear combination of the known sample values around the point to be estimated. The interpolation process determines the value of the points at grid intersections to have decimal figures. Hence, the values are rounded to the nearest integer which is the norm for representing pixels brightness within a raster image.

Kriging allows the user to derive weights that result in optimal and unbiased estimates. It attempts to minimize the error variance and set the mean of the prediction errors to zero so that there is no over- or under-estimates. An important feature of Kriging, as compared with other image or surface interpolators, is that it gives an estimation of the error at each interpolated point, thus providing a measure of confidence in the modelled surface. A thorough theoretical explanation of Kriging interpolation is beyond the scope of this paper and the reader is referred to [3] for the theory and applications of this interpolation technique in the particular areas of digital imaging and remotely sensed data.

5. TESTS AND RESULTS

The proposed enhancement process was tested for video imaging applications using simulated data. In this controlled experiment, the 'true' image was known prior to the enhancement and thus the accuracy of the enhancement and some of the factors that would degrade the process could be investigated and quantified. In general, the aim was to evaluate visually and statistically the performance of the proposed enhancement.

A high-resolution image referred to as the face was scanned and stored as a .tif file with no compression applied to it. This image is shown in Figure 9(a). The initial image was captured as a colour image and was modified to contain only 255 levels of gray-scale using the image processing toolbox of Matlab 7.1. The size of the image was 100^2.



(a) (b) (c) (d)

Figure 9: The original high resolution image (100^2) of the face (a) whereas (b) is one of the 50 down-sampled and compressed images (25^2) used in the enhancement. (c) is the contour representation of (b) whereas (d) is the enhanced composite derived from merging the contour representations of 50 low-resolution images as in (c).

Fifty (50) low-resolution .tif images were acquired by randomly repositioning and scanning the original image, avoiding unnecessary rotations. The scanner resolution was set to create coarse images having 4 times less pixels linearly than the original, thus creating ten images having a size equal to 25^2. The 50 images were then MPEG (Moving Pictures Expert Group) compressed for a compression ratio of approximately 10 [2].

The main reason a conventional off-the-shelf scanner, rather than a standard digital camera, was used for these tests was the flexibility the scanner offered with respect to the selection of the format of image storage and the scanner's optical resolution. Uncompressed images could be retrieved at various scanner resolutions and be stored in any desired image format such as TIF.

An image thus obtained was considered to be an image which would preserve the basic integrity of its colour information. The digital cameras to which the author had access compressed their images and may have introduced artefacts during that compression process. The use of the scanner allowed any set of images enhanced by the algorithm to be directly compared if required with an 'equivalent' uncompressed TIF image from the scanner.

Rotations were not applied to the images as they would have added extra parameters to the enhancement process and may have detracted from the strength of the conclusions reached in the experiments. Correlation obviously exists amongst a video camera and orientation parameters such as tilts, rotations and affinity/obliquity of the sensor, and, in a controlled experiment where the aim is to demonstrate the use of a process to enhance image resolution *per se*, it was thought imprudent to introduce such complications.

An example of the low-resolution image and its associated contour version are shown in Figure 9(b) and 9(c) respectively. The contour increment for all the down-sampled images was selected to be 5 gray-scale intensity values ranging between 25-225, thus producing approximately 40 contours per low-resolution image. This interval would include all the gray-scale variations of the input images. Figure 9(d) shows visually the results of merging the contour representations of the 50 low-resolution images.

The enhancement process described in section 4 was applied to the 50 compressed images using a spatial enhancement factor (ratio between low-resolution and high resolution grid sizes) of 4. The r.m.s. of the differences between the enhanced composite and the original .tif image of the *face* was ± 5.4 with maximum and minimum values ranging between +12 and -9 gray-scale levels respectively.

In addition, the number of contour vertices processed to attain the result in Figure 9(d) was approximately 45% less than the total number of pixels included in the initial 50 input images, and only 35 of the initial 50 contour representations were used as more than this number did not contribute in improving the accuracy of the enhancement.

6. DISCUSSION AND CONCLUSIONS

Notable findings encountered in this study are:

- The conversion of a set of low-resolution digital images of faces into contour maps, and combining these map representations, may be used to produce a composite raster image having more details than any of the individual low-resolution images.
- The process of generating contour data comprises the step of assigning coordinate values to pixels in the raster format image data and interpolating between pixels to find the coordinates of points in the path of a contour having a given brightness value.
- A method for enhancing the resolution of a compressed sequence using a Kriging interpolation approach has been presented where the alignment or registration of the low-resolution images required for the enhancement relies on a novel registration method that can achieve fractional accuracies of +/-0.01 pixels.
- The application of the enhancement process has been demonstrated in 2D using controlled experiments which simulated a video sequence.
- The contour approach to multi-frame image enhancement allows for redundant contour data to be filtered and discriminated from the final enhancement process thus improving processing time while producing accurate results.
- Refinements to the proposed method are being undertaken to increase the accuracy achievable for a variety of scenes and dynamic ranges (including bi-tonal imagery).

- More research is required to assess the accuracy of the enhancement process in the presence of (a) rotations amongst the input images and the presence of random noise.
- Tests related to investigating the performance of a contour approach to image enhancement whereby both sensor and object are dynamic, and the illumination is non-uniform, are presently being undertaken.

REFERENCES

[1] Bonham-Carter G. F.: Geographic Information Systems for Geoscientists: Modelling with GIS. Vol. 13 of Computer Methods in the Geosciences. Elsevier, Butterworth-Heinemann. 398 pages. 2006.

[2] Bovik A.: Handbook of image and video processing. Elsevier Academic Press. Al Bovik editor. 972. 2007.

[3] De Jong S. M. and van der Meer F.D.: Remote Sensing Image Analysis Including the Spatial Domain, Kluwer Academic Publishers, pp. 360. 2004.

[4] Duperet, A.: Image Improvements, Chapter 2, Digital Photogrammetry. Michel Kasser and Yves Egels editors, Taylor & Francis Publishers. p.p. 351: 79-100. 2002.

[5] Elder J. H. and Goldberg R. M.: Image Editing in the Contour Domain. IEEE Transactions on Pattern Analysis and Machine. Vol. 23 No.3. 2001.

[6] Fryer J. and McIntosh, K.L.: Enhancement of Image Resolution in Digital Photogrammetry. Photogrammetric Engineering & Remote Sensing", Vol.67, No.6, pp.741-749. 2001.

[7] Gonzalez R. C. and Woods R. E.: Digital Image Processing. Prentice Hall, 954 pages. 2008.

[8] Sicairos G. M., Thurman S. T. and Fienup R. J.: Efficient sub-pixel image registration algorithms" Opt. Letter. 33, 156-158. 2009.

[9] Smith M. Goodchild F. and Longley P.A.: Geospatial Analysis: A Comprehensive Guide to Principles, Techniques and Software Tools. 3d Edition. The Winchelsea Press. pp. 560. 2009.

[10] Spiegel M. R., Stephens L.: Theory and Problems of Statistics, Schaum's Outline Series, McGraw-Hill Book Company. pp. 556. 1999.

[11] Vandewalle P., Süsstrunk S. And Vetterli M.: A Frequency Domain Approach to Registration of Aliased Images with Application to Super-Resolution. EURASIP Journal on Applied Signal Processing (special issue on Super-resolution), Vol. 2006, Article ID 71459, pp. 14. 2006.

[12] Wang S., Ge F. and Liu T.: Evaluating edge detection through boundary detection. EURASIP Journal on Applied Signal Processing, vol. 2006, pp. 1–15. 2006.

[13] Weeks, A. R.: Fundamentals of Electronic Image Processing. SPIE Optical Engineering Press, Bellingham, Washington. pp.570 pages.1996.

[14] Zitova B. and Flusser J.: Image registration methods: a survey. Image and Vision Computing. Elsevier Publisher, 21, June, pp. 977-1000. 2003

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

Creating a Marine Habitat Geoexploratorium using Digital Globe Technologies

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ABSTRACT

Recent developments in digital technology have led to the collection and production of an unprecedented amount of spatial and multimedia information. However, presenting such large amount of diverse information in an understandable and accessible format has now become a major challenge. Digital globes represent a useful canvas through which complex spatial information can be communicated and explored by providing free access to geographically referenced large repositories of spatial data, anywhere on the planet.

This paper describes an example application of how this technology can be applied to bring together various sources of information, through an interactive environment, to promote community awareness. The project, entitled “My Coast” is based on the “Geoexploratorium” concept. It aimed to integrate various information mediums, such as coastal bathymetry and marine habitat data, multimedia images and videos, and text information into a digital globe. This approach investigated the use of a combination of commonly available GIS, and multimedia software tools to incorporate this costal data within the Google Earth environment as place-mark balloons, screen overlays and interactive guided tours. This information package was then made accessible online via a light KML file, which read data from a web-server and allowed users to explore their coastal environment.

The structured approach presented in this paper provides an example of the potential and limitations or currently available tools to harness the power of digital globes to present scientific data to wider audiences.

1. INTRODUCTION

An increasingly salient community educational problem is that many modern risks are not easily visible or understandable to us as information [1], for example those related to sea level rise or marine conservation. Therefore, community awareness, in this case coastal education, is becoming a significant component of environmental policy across the globe. It is being used as a means of empowering local communities to understand, identify with, and, ultimately to become active participants in complex management situations [2]. To encourage the public to participate in managing their coastline, a digital globe environment has been deployed based on the concept of an online interactive “Geo-Exploratorium” [3].Such an environment enables visual interaction, which is more effective than more traditional mapping mediums of communication for them to obtain the desirable information [4]. Digital globe technology allows concept application to include exploratory information-landscape comprising marine bathymetry, habitat classification, underwater videos, and other multimedia content. The use of this technology is advantageous because it is popular, freely available for viewing, user-friendly and is easy to maintain [5, 6]

We believe that digital globe technology, in this case Google Earth, is a useful tool to create interactive exploratory data interfaces. A combination of digital globe, GIS and multimedia technology can bring together various sources of information that can promote community awareness and empower local communities to understand, identify with and, ultimately, allow active participation in complex situations of coastal management.

2. DIGITAL GLOBE TECHNOLOGY – GOOGLE EARTH

Fuller’s concept of Geoscope in 1962 and MIT’s Aspen Movie Map multimedia project in the 1970s were among the few early introductions of digital representation of the Earth, but Giger’s “Plate Earth” released in 1998 was the first commercial version of digital globe technology, to display dynamically updated Earth data. The digital globe technology was later dominated by Google Earth and has been downloaded more then 500 million times in less then five year [7]. Digital globe technology was used to build the “My Coast” because it provides free and interactive access to specific functionalities such as zooming, panning, and interactivity. Previously, these functionalities were only available in traditional Geographical Information Systems (GIS), such as access to contextualising high quality satellite and aerial imagery as well as terrain data. The technology also represents an ideal platform, which is free, popular and open-source, through which local and large scale spatial data can be presented [8, 9]. Out of the plethora of digital globes currently freely available online, we chose Google Earth Keyhole Markup Language (KML) as our development platform, based on previous investigative work on digital globes and their specific functionalities and potential [8, 10]. KML is also an Open Geospatial Consortium (OGC) standard [11] and KML files are interoperable with many other digital globes and can be viewed on Linux, Mac and Windows operating systems. There are now numerous examples of scientific data being displayed in Google Earth and researchers with different expertise are collaborating via Google Earth [12]. The Department of Primary Industries (DPI) Future Farming System Research (FFSR) Division initiated digital globe work in the early 2000s and these efforts continue to evolve with the development of Keyhole Markup Language (KML) representations of scientific data. KML files produced by FFSR are in regular use by DPI stakeholders and decision-makers. For example research and development has been undertaken in developing a number of climate change future communication tools to enable farmers and policy-maker the opportunity to explore the likely impacts of climate change on land suitability [13].

3. GEOEXPLORATORIUM – THE PROJECT

3.1. Concept

The concept behind The My Coast project was to develop an interactive visual output from a complex multi-format coastal database. As described in Figure 1, a broad range of data formats and processes have been taped and delivered through Google Earth with the help of KML (Keyhole Markup Language) based Google Spreadsheet Mapper application. The Spreadsheet Mapper application would allow any non-technical team member from the host organisation (DSE-Department of Sustainability and Environment) to maintain the product without obtaining any specific GIS or scripting knowledge. The approach will help DSE to update any further information with little technical expense required to maintain the digital globe marine habitat product.

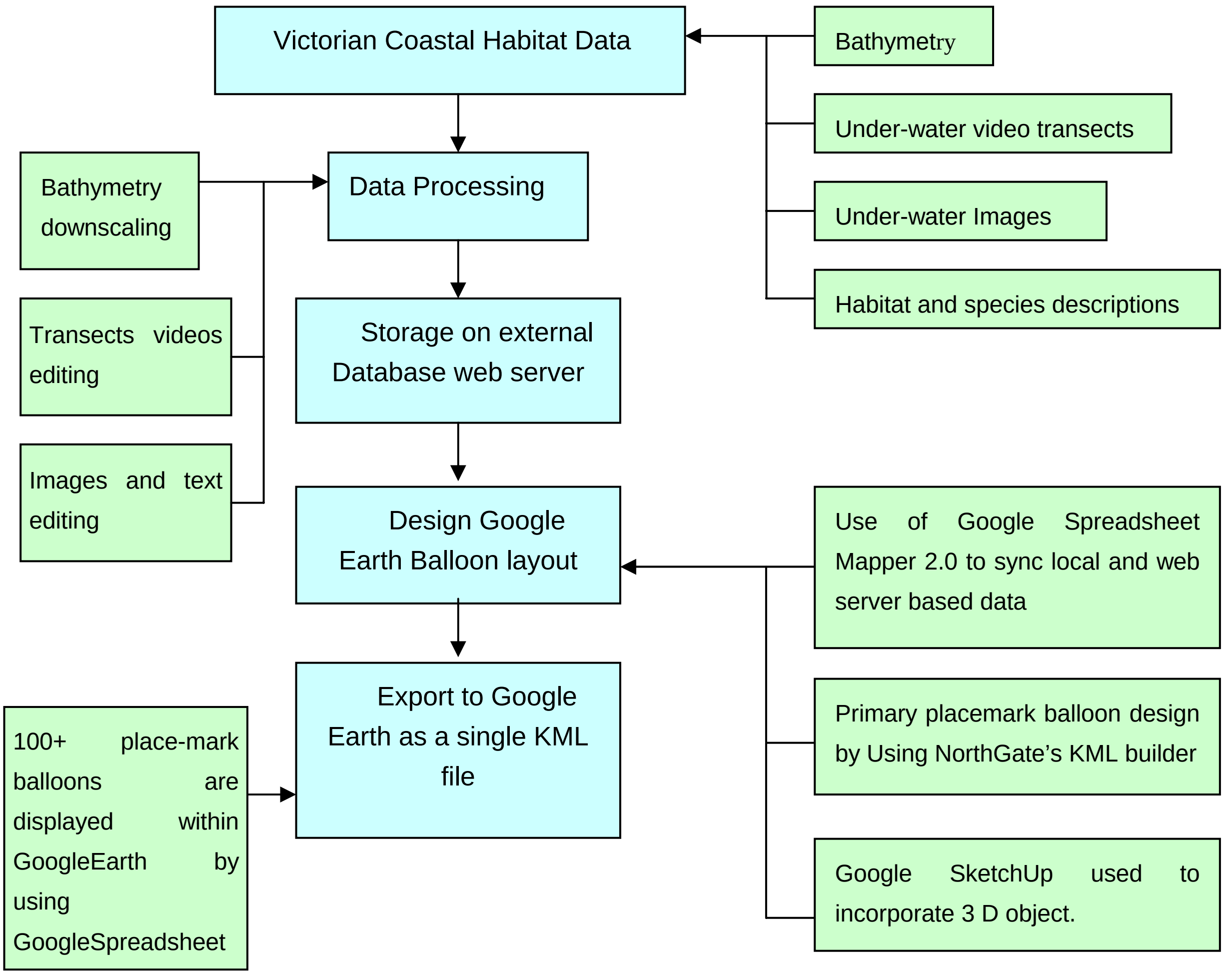


Figure 1 : Chart describing the workflow process used in the development of the Geo-Exploratorium

3.2. Data and region

The Department of Sustainability and Environment (DSE) and the Department of Primary Industries Fishery Division provided source data for this project in three different forms, (1) Coastal Bathymetry data for the Port Philip Bay and the Western coastline of Victoria (extending from Point Lonsdale to Cape Otway). (2) Geo-referenced high definition (HD) Video and still images extracted from video transects performed by DPI Fisheries to ground truth bathymetric information and calibrate underwater habitat mapping programs. (3) Still images and text information about specific habitats, marine plants and animal species found on the Victorian coastline.

Nineteen different types of marine biota can be found on the Victorian coastline (see Table 1), primarily between the depths of 0 to 20m. The DPI Fisheries division at Queenscliff combined LiDAR data and manual ground-truthing information, collated by an underwater camera fitted boat, to identify where each of this biota was found along the coast. To structure marine habitat information in a more manageable manner, these nineteen biota classes have been merged into twelve coastal habitats by combining similar biota classes as shown in Table 1.

Depth Range:		Biota Type Classes:	Habitat	Habitat/Feature name
0 m	1	Neptunes Necklace (*Hormosira banksii*)	1	Inter-tidal Rock Platform
0-5 m 0-10m 0-10m 0-10 m	2 3 4 5	Bull Kelp (*Durvillaea potatorum*) Giant Kelp (*Macrocystis angustifolia*) Cray Weed (Phyllospora comosa) Common Kelp (Ecklonia radiata)	2	Shallow Kelp forest
10-15 m 10-25 m	6 7	Cray Weed/Common Kelp (*Phyllospora comosa*/*Ecklonia radiata*) Common Kelp (*Ecklonia radiata*)	3	Deep Kelp Forest
0-15 m >15m 0-20 m	8	Invertebrates	4	Shallow Invertebrate Reef Deep Invertebrate Reef Invertebrate Sands
0-20 m 0-20 m 0-20 m	9 10 11	Mixed brown algae Mixed red algae Mixed green algae	5	Mixed Algal Reef Mixed Algal/Invertebrate Reef
5-10 m	12	Amphibolis antarctica	6	Sea Nymph Meadows
0-20 m 0-20m	13 14	Eel Grass *(Heterozostera* spp) Eel Grass *(Zostera* spp.)	7	Seagrass Sands
0-20m	15	Posidonia australis	8	Strapweed Meadows
0-20m	16	Broad Leaf Seagrass (*Halophila australis*)	9	Paddle-grass meadows
0-20m	17	Urchin barrens	10	Urchin Dominated Reef
0-20m	18	Rhodoliths	11	Rhodolith beds
0-20m	19	Bay sediments	12	Bay Sands

Table 1: List of twelve coastal habitats used in the project

3.3. Data processing

The Bathymetry information was provided by DSE for both the Cape Otway to Point Lonsdale area (Figure 2a) and the Port Philip Bay (Figure), as a projected ArcGIS grid at a 5m resolution. To provide a better depth perspective to the bathymetry, it was overlaid with its matching hill shade layer, calculated using ESRI ArcGIS 9.3. The export process of the bathymetry and hill-shade data was done in three successive steps.

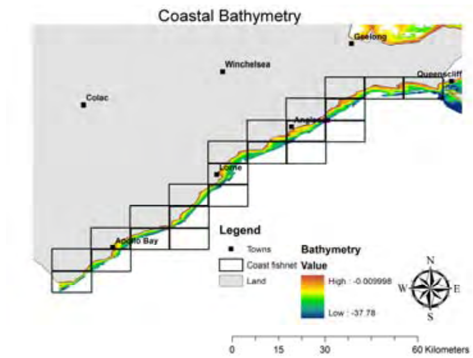


Figure 2a: Fishnet above the Coastal area

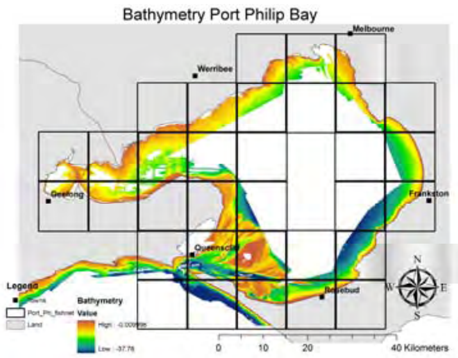


Figure 2b: Fishnet above the Port Philip Bay area

1) GIS data preparation: The raster data format and extent of the provided bathymetry was not supported by KML and in order to be visualised in Google Earth, raster datasets need to be converted to smaller geo-referenced tiled images in .png and .pnw file format. Such files can be exported directly from ArcMap 9.3. To create tiles of a consistent extent, two separate regular grids have been created of square polygons or “fishnets”, covering the Port Philip bay and the costal areas (Figure 2a and Figure 2b). These fishnets where then converted to a polygon format and buffered by 100 meter to make sure the tiles overlapped properly in Google Earth. These fishnets were then used to clip each of the bathymetry and hill shade layers to produce individual tiles by using Python script. This process was run for the Port Philip Bay and the costal area producing 55 tiles for bathymetry and hill-shade component each.

2) Data conversion from raster to image format : Each set of tiles, produced as a result of the clipping of the hill shade and bathymetry data, was displayed into the ArcMap interface and exported individually from ArcGIS using the export command to product a .png and .pnw file. This repetitive process was semi-automated using the Visual Basic Application (VBA) script. This process led to the production of 110 images in the .png format at a resolution of 300 dpi.

3) Data tiling and export to KML: In order to allow Google Earth to easily display these images, each image was further tiled using the SuperOverlay (2.0.3) software. Image tiling was done with a specific level of detail which addresses concern of users using high-resolution bathymetry data to identify local fishing spots or un-fished reef sections. This setting resulted in the disappearance of the bathymetry data from the screen as users viewpoint reached below 1 km of altitude. The tiling process in super overlay also resulted in the production of KML files that brought together all produced tiles and allowed them to be viewed in Google Earth. The produced tiles and KML were then uploaded onto a remote web server and referenced into main KML interface via an imbedded hyperlink.

4) Video, Image and text data processing: Transect videos and images were captured by DPI Fisheries Victoria based at QueensCliff, as ground-truthing reference for the automatic habitat classification from the LiDAR data. All the transect videos and images were captured with a high definition under-water camera. More than 50 high-resolution videos and 100 images from various locations on the Victorian coastline were provided for the project, in combination with a Microsoft excel file identifying the geographic coordinates of each transect. The provided high definition videos had to be resized and converted into flash file format to allow them to easily stream from a web server. In addition, all the video transects and images are provided with respective text information representative of 12 marine habitats found along the Victorian Coastline and were uploaded on the remote web server to be used as part of the main KML interface.

4. ROLE OF GOOGLE (EARTH AND SPREADSHEET MAPPER)

A “Master KML” file, that linked, referenced and organised each component of the dataset based on their physical location and habitat types to bring together the image, videos, text and bathymetry components of the My Coast. For this purpose, KML placemarks and their associated balloon functionalities have been used. These functionalities allowed authors to associate each location of interest along the Victorian coastline with a square or rectangular HTML window where videos, images and text information are displayed and HTML links (linking to external web pages, other KML files or to other placemarks in the Geo-Exploratorium interface) are embedded.

4.1. Design of the HTML template controlling the Balloon placemarks

A set of five HTML templates were applied to each component of the interface to provide consistency in the structure and appearance of the Marine Geo-Exploratorium. These HTML templates were developed using the freeware NorthGate’s KML Builder 1.0 Beta. This software allowed development and testing of KML balloons via a Graphical User Interface (GUI) and greatly simplifying KML interface development. The HTML code generated in the interface was then extracted from the NorthGate’s KML language interface and used in the development of master KML file.

4.2. Application of the template to locations of interest

The development of a master KML file was structured by using Google Spreadsheet Mapper 2.0. Spreadsheet Mapper is a Google Doc’s web based application, which allows the creation of placemark layers for display within Google Earth and Google Maps. Spreadsheet Mapper provides an easy and efficient way to create a large number of KML placemark balloons and format their associated balloons based on pre-defined templates. It also enables developers to link-in text, images, videos, and hyperlinks to specific placemarks via a spreadsheet interface, while generating the corresponding KML code in the background.

All of the developed KML balloon templates were imported into Google Spreadsheet Mapper and inserted into separate templates. Each of the generated templates was then being attributed to specific placemarks via the “PlacemarkData” worksheet.The “Placemark data worksheet” provided a platform to consolidate all text information and media related to specific locations of interest and format them according to pre-defined or imported balloon templates. This template based spreadsheet structure was seen as particularly valuable as it allows addition of new placemarks and the My Coast interface could therefore be expended to cover more locations. Currently, The My Coast contains more then 50 placemarks spread across the Victorian coastline. The My Coast KML interface provides access to a very large amount of data (over 1 Gb), which could therefore not be packaged into a single downloadable file. The authors tired to overcome this limitation by designing KML, which can dynamically fetch the data from remote web server. This server technology allowed authors to produce a very small KML file (<1kb) that can easily be downloaded from Victorian Resource Online (VRO) web site or Emailed to stakeholders.

4.3. Development of Guided tours:

One KML introductory audio guided tour, using the “record a tour” Google Earth functionality has been developed and included within the My Coast KML to improve the user’s experience and familiarise them with the data provided in the interface.

5. INTERFACE DELIVERY

The Geo-Exploratorium interface is composed of multiple interlinked elements composed of:

1. A welcome balloon
2. A suite of habitats and species exploration balloons, and
3. An “About us” balloon.

5.1. A welcome balloon

The welcome balloon (Figure 3) displays automatically upon opening the KML file in Google Earth. This balloon displays a short introductory sentence to the My Coast and allows users to explore twelve Victorian coastal habitats by a hyperlinked clickable image, which activation transfers the user to the corresponding habitat exploration placemark.

Figure 3: Flash screen of the Marine Geo-Exploratorium product

5.2. Habitat and species exploration balloons

The navigation structure of the Geo-Exploratorium interface is illustrated in

Figure **4**. Each of the habitat icons displayed in the welcome balloon (Figure 3) is linked to a corresponding habitat description balloon (

Figure **4**).

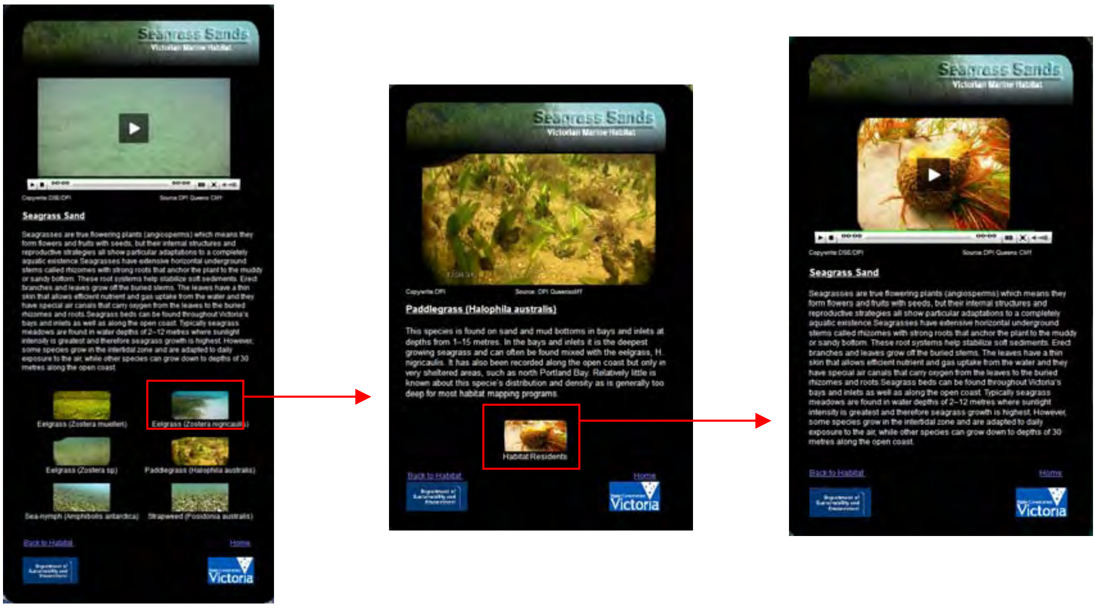
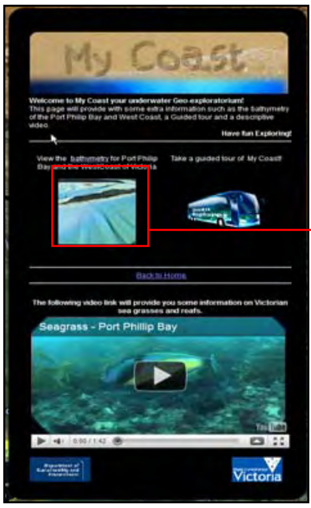


Figure 4: Marine Geo-Exploratorium balloon navigation pattern.

Each of these habitat description balloons contains a brief text description of the costal habitat, a short video clip specific to this habitat and clickable species icons linking to species-specific balloons containing more information on species characteristics of the chosen habitat residents. Each of the species-specific balloons displays an image of the focus species, a short text description and an image hyperlink to a further “Habitat resident” balloon. The Habitat resident balloon contains a list of all species associated with the habitat of interest and a flash animation displaying images of these species. Although, the Welcome balloon was designed as the main navigation portal to the My Coast, the information on each of the 12 marine habitats can also be accessed by directly clicking on habitat placemarks along the coastline by users.

5.3. About us balloon

The My Coast KML interface also contains an “About Us” balloon (Figure 5a) that can be accessed from the Welcome screen or by clicking directly on the “About us” placemark. This balloon contains two clickable icons providing access to (1) the bathymetry data layer (**Figure** 5b) for the Victorian coastline and Port Philip Bay and (2) the audio guided tour of the Geo-Exploratorium. The bottom portion of this balloon also displays external video providing information on Victorian sea grasses and reefs.



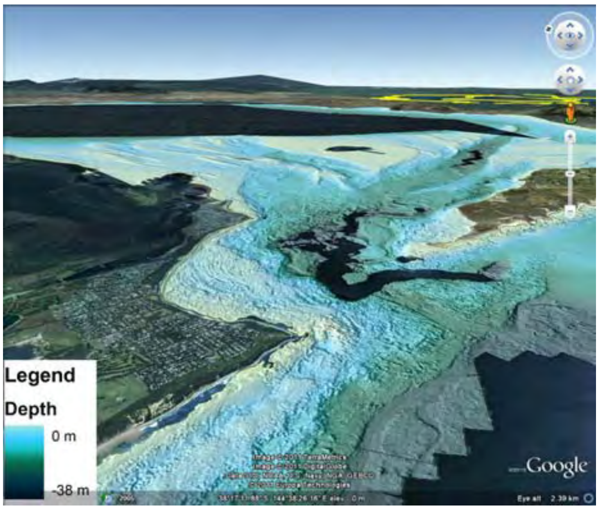


Figure 5a: The “About us” balloon. Figure 5b: bathymetry data within the Google Earth interface.

6. CONCLUSION

The My Coast has delivered an interactive marine habitat visualisation and exploration product. It provides a portal through which users can access: bathymetry, videos, textual content, and image data relative to the 12 selected marine habitats situated along the Victorian coast. In this project, Google Earth has been customised to provide an easy-to-use interface for the broader community. It also allows the product design to be extensible and can be easily altered to incorporate new locations, habitats, or supporting datasets. This permits end users to explore product features interactively through an intuitive Google Earth interface.

The My Coast highlighted the potential of Google Earth based visualisations to disseminate and communicate various types of data. We believe a similar approach could be applied to various datasets, such as soil pit information, borehole data, locust or any other pest invasion, bushfire, and vegetation management. Ultimately, this will help communicate research findings to a range of end users ranging from policy-makers to the general public. It is recommended that the evaluation of the Marine Geo-Exploratorium be undertaken to understand its usability and usefulness as an educational and public resource.

The experimental application also provided a broad insight for future opportunities and limitations of the technological combinations. The Google Earth balloon interface can be refined by using Adobe Flash instead of HTML. Flash can provide better balloon layout with much smoother navigation but it surely need scripting capabilities. The limited number of template was one of the main limitations of Google SpreadSheet Mapper. The over structural flow of the SpreadSheet Mapper is also complex in nature and difficult to understand for non-technical person. Lack of quick preview capabilities and version history are among few noticeable drawbacks. Limited Interactivity of the Google Earth Screen overlay and objects animations were few constrains from Google Earth technology.

7. ACKNOWLEDGEMENT

The Authors are thankful to the DSE for providing such an opportunity to demonstrate the Geo-Exploratorium concept and grateful to Sean Blake from DPI fisheries for providing images, video transacts and text information for the project and his regular constructive feedback.

REFERENCES

[1]. Slovic, P., *Perceived Risk, Trust and Democracy.* Risk Analysis, 2006. **13**(6): p. 675-682.

[2]. Snively, G. *Thinking like an ocean: marine education principales that ensure coexistence between people and nature*. in *5th EMECS Conference*. 2001. Japan: Elsevier.

[3]. Cartwright, W.E., B. Williams, and C. Pettit, *Realizing the Literate Traveller.* Transactions in GIS, 2007. **11**: p. 9-27.

[4]. Wim Fikkert, M.D.A., Torsten Bierz and T. J. Jankun-Kelly, *Interacting with Visualizations*, in *HUMAN-CENTERED VISUALIZATION ENVIRONMENTS*
2007, Spinger. p. 77-162.

[5]. Butler, D., *The web-wide world.* Nature, 2006. **439**(7078): p. 776-778.

[6]. Chen, A., et al., *Visualization of A-Train vertical profiles using Google Earth Computers and Geosciences*, 2009. **35**(2): p. 419-427.

[7]. Bailey, J.E. and A. Chen, *The role of Virtual Globes in geoscience* Computer & Geoscience, 2011. **37**(1): p. 2.

[8]. Aurambout, J.P., C. Pettit, and H. Lewis, *Virtual Globes: the next GIS*, in *Landscape Analysis and Visualisation*, C. Pettit, et al., Editors. 2008, Springer Berlin,: Heidelberg. p. 509-532.

[9]. Peng, Z.-R., *Internet GIS for public participation.* Environment and Planning B: Planning and Design, 2001. **28**(6): p. 889-905.

[10]. Aurambout, J.-P. and C. Pettit. *Digital Globes: gates to the digital Earth*. in *Digital Earth Summit on Geoinformatics 2008: Tools for Global Change Research* 2008. Potsdam, Germany: Wilchmann, Heidelberg.

[11]. Consortium, O.G., *Open Geospatial Consortium KML*, T. Wilson, Editor. 2008. p. 251.

[12]. Ballagh, L.M., et al., *Representing scientific data sets in KML: Methods and challenges* Computer & Geoscience, 2011. **37**: p. 57-64.

[13]. Aurambout, J.-P., et al., *Simplifying climate change communication: An application of data visualisation at the regional and local scale*, in *Geospatial Vision 2 - New Dimensions in Geovisualization and Cartography*, A. Moore and I. Drecki, Editors. in press: Auckland, NewZealand.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

CLASSIFICATION AND USE OF LANDFORM INFORMATION TO INCREASE THE ACCURACY OF LAND CONDITION MONITORING IN WESTERN AUSTRALIAN PASTORAL RANGELANDS.

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ABSTRACT

Historically landforms have been mapped from field-based surveys or using stereo aerial photographs. Information about landforms plays an integral role for landscape evaluations, suitability studies, erosion studies, hazard predictions and various fields of landscape and regional planning. First, techniques and software were explored to extract primary topographic attributes from a digital elevation model (DEM): elevation, slope, profile curvature and plan curvature. Second, LandSerf software was employed to classify the DEM into landform types through semi-automated feature extraction. Six landform classes were produced: pits, channels, passes, ridges, peaks and planar. Experimental methods established the most suitable sampling window scale and slope tolerance. Curvature was not used in the classification process therefore no differentiation was found between slope types: upper, mid, and lower slope. Object based image analysis was tested using Landsat TM imagery. The imagery was segmented into areas with similar shapes. The boundaries can be forced to replicate those of landscape variables including the landform data produced in LandSerf, land system boundaries and available land unit boundaries.

This research provides evidence that available software can be used to map landform elements at the land subsystem level where currently data only exists at a land system level. This research aims to increase the quality and quantity of available land condition data that can be used in monitoring conditions of pastoral leases. Greater ability to provide accurate results on pastoral conditions will enable the lessee to better manage their land and increase productivity.

1. INTRODUCTION

This research is a study into landform patterns and landform elements at the land subsystem level to areas where the land surface is currently only mapped at a land system level. A study area was chosen to explore land condition information. Geographic Information methods were investigated to use this information to develop data that could eventually be applied to other pastoral rangeland areas of Western Australia. The outcome of this research is to provide higher resolution data capturing a greater range of spatial variation that can be incorporated into land condition monitoring projects including Pastoral Lease Assessment using Geospatial Analysis (PLAGA) and field surveys.

Various plant species have a variety of effects on rangeland ecosystems. These effects are exemplified predominately through animal grazing, fires and the regeneration of plant species (McKenzie 2004). Traditionally information of these effects was acquired through field surveys by Department of Food and Agriculture, Western Australia (DAFWA) that are not always practical due to lack of accessibility in remote areas, cost and time considerations. Geographic information systems/science (GIS) enables these effects to be monitored through projects such as PLAGA using satellite imagery and remote sensing techniques. PLAGA monitors grazing land condition and other natural phenomena including fire (Robinson, pers. comm., 2010). To monitor vegetation the surrounding and underlying landscape also need to be considered. Particular plant species may thrive after a fire initiated by an increase in grassland caused by cattle feeding on woody plants in a certain area but also a plant will thrive dependent on soil condition and the terrain of the landscape.

2. BACKGROUND

The WA rangelands can be divided into five regions: Kimberley, Pilbara, Gascoyne, Murchison and Goldfields. The research reported here focuses in the East Kimberley regional district of the Kimberley (Figure 1). The Kimberley region covers a total area of approximately 422,000 km² occupying one sixth of the entire state (Department of Regional Development and the North West and Kimberley Regional Development Advisory Committee (WA) 1986). The East Kimberley is comprised of several river catchment areas. The Ord River Catchment was chosen due to availability of land condition information at the land system scale. The data covers three stations – Ivanhoe, Carlton Hill and Bow River Stations. Due to the extent of the Ord River Catchment initial studies have be conducted in the Bow River Station area that was chosen for the diversity in topography and its relative central location.

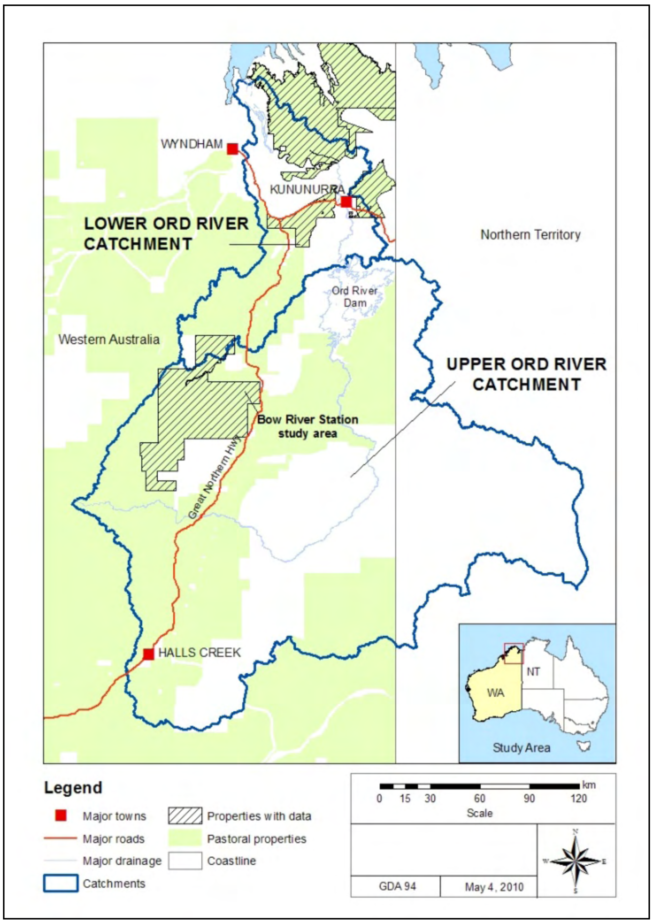

Figure 1: Bow River Station study area.

In general, the pastoral leases are extremely large with an average size of 1,850 km². A lease requires regular inspection although if a lease has no identified land condition problems then inspections are only performed once every six years. Around 75 leases are inspected annually by DAFWA at an estimated cost of $13,000 per lease. Lease reports produced by DAFWA are prepared for the WA Pastoral Lands Board (PLB), which administers pastoral lands under the WA Land Administration Act.

A large amount of research surrounds techniques and models that have been tried and tested for landform classification since the process of landform classification was first instigated by Gauss in 1828. There are two main spatial classification techniques used in GIS analysis; supervised and

unsupervised classification. These classification techniques require an input raster to analyse (e.g. Digital Elevation Model (DEM)) and the classes or clusters into which to group the data. The bases of class allocation for this analysis have been defined according to the *Australian Soil and Land Survey, Field Handbook*, where landform elements are classified as either: crest, ridge, flat, depressions and slopes (Speight 2009).
Attempts have been made to derive land unit information in the Ord River Catchment in the past. The main problem was that datasets were not at a high enough resolution to detect patterns in the land surface of an appropriate quality for precise land use classification. The model tested outside the "training data only predicted the correct land unit 3% of the time" (Schoknecht 2003).

3. METHODOLOGY

The methodology for this research can be divided into four steps that are as follows:

- Define landform features at a land subsystem level;
- Investigate techniques for extracting landform patterns and landform element from a digital elevation model;
- Investigate landscape models using other variables i.e. geology, land systems, drainage and land use data;
- Define a model to be used to extend landform features to other pastoral rangelands in WA

These steps can be represented as a structure chart that identifies the initial DEM and the process required to achieve data at a land subsystem level suitable for land condition monitoring techniques.

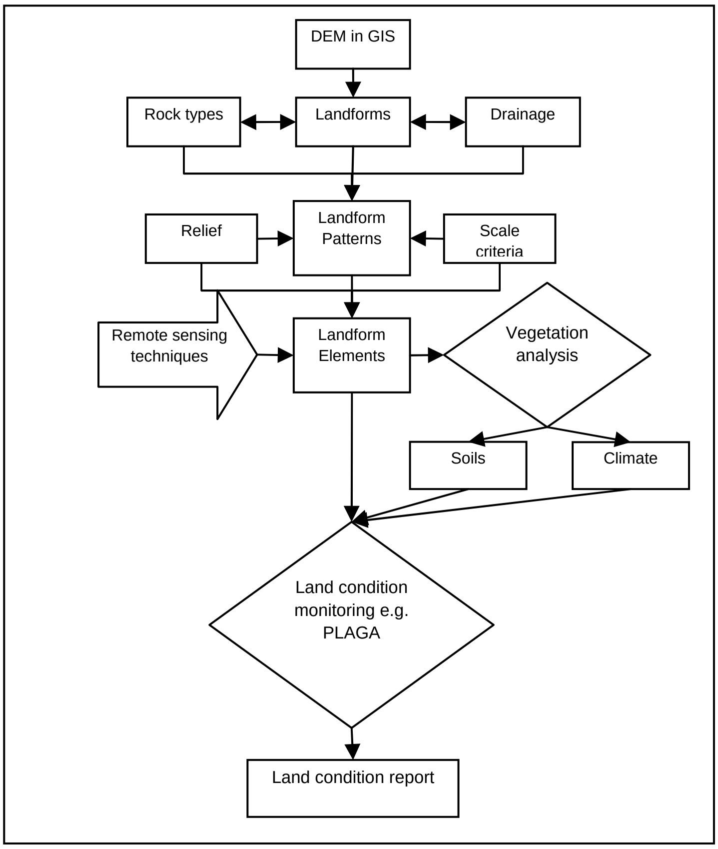

Figure 2: Methodology structure chart.

Initial research investigated the capabilities of GRASS, ArcGIS and LandSerf software to perform semi-automated landform feature extraction using unsupervised classification techniques. GRASS was found to have limited geomorphological processing capabilities in comparison with LandSerf and was rejected from further spatial analysis. LandSerf offers a feature extraction tool suite that allows user specification of window scale, slope tolerance and curvature tolerance (Wood 2009). LandSerf semi-automatically classifies a digital elevation model (DEM) into six classes – peaks, channels, plains, passes, pits and ridges. These classes can then be exported as shapefiles, rasters and various other data formats suitable for a variety of software. To find the ideal tolerance levels for landform classification, LandSerf offers a set of query tools. Using the query tools LandSerf parameters for the Bow River Station DEM were defined suitably. Due to the complexity of ridges and passes it was decided to simplify classification by classifying primary landforms channels and peaks first and to then extract and define more complex landforms with slope and curvature individually. A single landform raster was created in LandSerf. This landform raster was then imported into ArcGIS software.

ArcGIS was used for individual feature extraction of raster data, subset data analysis, preparation and presentation of findings and results as maps. Landform data was imported into ArcMap as a single raster that was broken into separate landform element rasters to be used in a comparative study. The study involved visual analysis of individual landform rasters with a variety of data and imagery to determine similarities and differences. Comparisons were made with Landsat 2002 imagery, geology, land system and land unit shapefile data both in ArcMap and ArcScene for two and three dimension perspectives respectively.

Due to arising limitations found during post-processing of LandSerf data to acquire acceptable accuracy for landform element class boundaries an investigation was made into Object Based Image Analysis (OBIA). The advantage of OBIA is the use of many different image layers in the analysis and classification processes. Data were loaded as image layers and thematic data into eCognition. The image layers included individual and combined landform rasters, slope and curvature rasters, a mosaic and clipped DEM for Bow River Station and Landsat 2002 imagery. The thematic data included land system, land unit, drainage and geology shapefiles. The Landsat 2002 image, as provided, did not provide enough spectral information (only Bands 1, 2, 3) so Landsat 5 TM imagery was downloaded from the US Geological Survey (United States Geological Survey. 2011) website for the Bow River Station area. The first step in eCognition was to segment the data using one or many of the image layers. First, segmentation was explored using the 30 m resolution DEM. The scale parameter was chosen by trial and error with an acceptable scale found to be 25. The newly created segmented layer was named “DEM”, defined by elevation only. Land units were then used to segment the land surface to aid classification of the landforms. For classification to begin a class hierarchy was devised to define – channels, peaks, passes, pits, plains and ridges chosen to match those produced by LandSerf. Supervised classification techniques were used to classify the segmented data in eCognition. Pixel samples were selected that represented each landform element class. The classes were defined with threshold values of any or all of the image layers and/or of the thematic data. Conditions were also set for the classes that defined that individual landform (e.g. Channels: slope < 0). Once the threshold and conditions were defined a process was written that allowed the software to select every feature of that class. The eCognition classification process allows all classes to be classified together or using single class classification. The class layers can then be exported as shapefiles or rasters.

4. RESULTS

Classifications of landform information at a scale suitable to increasing land condition monitoring in Western Australian pastoral rangelands requires the results to be accurate and precise. The pastoral rangelands cover a large area that poses many problems within itself. The Kimberley pastoral rangelands are extensive and the topography is greatly diverse. Since it was not possible to classify the area as a single entity, small study sites were used for landform classification analysis. The study sites were chosen within pastoral leases where previous studies had produced land unit and land condition data.

Initially this research investigated the quality of the digital elevation model (DEM). The DEM available for this research consists of 30 m resolution Shuttle Radar Topographic Mission (SRTM) Level 2 Elevation Data. The main issue of classification with a DEM of this resolution is that some features will be compromised by the scale of the elevation data. Depending on the classifying software a sampling window needs to be chosen that is small enough to identify small landform features otherwise landform results would be estimated. This classifying effect has little influence on larger landform features classified at a larger or smaller scale. It was decided following analysis into other available elevation data that the 30 m SRTM DEM was the best source for topography in the study area.

The results from software analysis found strength and weakness for ArcGIS, LandSerf and eCognition. In each case, the DEM was input as the main data source. The DEM was then analysed using query tools and methods used to extract landform classes. It was found through an iterative process that LandSerf and eCognition were the best choice for landform classification for this research.

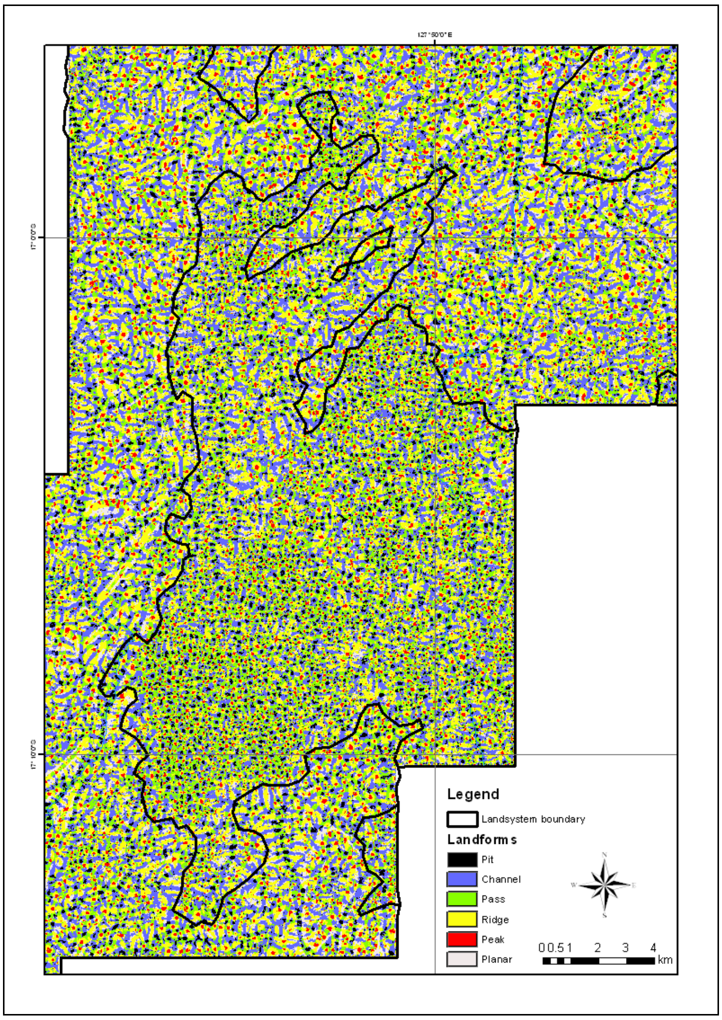

Figure 3: LandSerf landform results overlain with land system boundary data.

LandSerf produced results that divided the land surface into very small landform features (Figure 3). Most features appeared to correlate well with the DEM topography however some features appeared improperly grouped and incorrectly placed. Examples were channel features found to be discontinuous in landform classification. This discontinuity is likely due to errors or imperfections with the DEM and/or abrupt changes in elevation. These issues and abrupt changes in elevation then led to other classification errors including peaks allocated to low lying isolated points. According to Speight, (Speight 2009) peaks relate to hill tops defined by greater than 300 m elevation. The main cause of these problems was that only the DEM was used in the feature extraction process and more complex algorithms in the process were not possible. All LandSerf results were converted to ArcGIS GRID raster and added to ArcMap. The results were compared with land unit and land system data (Figure 3). Preliminary results using LandSerf identified that post-processing manipulation of the landform raster was required to achieve data that relates to other land condition information. Results found there were limitations with LandSerf unsupervised classification techniques.

Limitation of LandSerf initiated research into other software and techniques that might allow more input layers in the classification process. It was identified that slope, curvature and geology could aid classification of the Bow River Station area. If the classification process was forced to include such variables then better results might be found. ECognition is remote sensing software that allows input of various data types and provides a variety of classification techniques. Segmentation and supervised classification are the main functions of eCognition and results found using these techniques produced more precise channel and peak data (Figure 4).

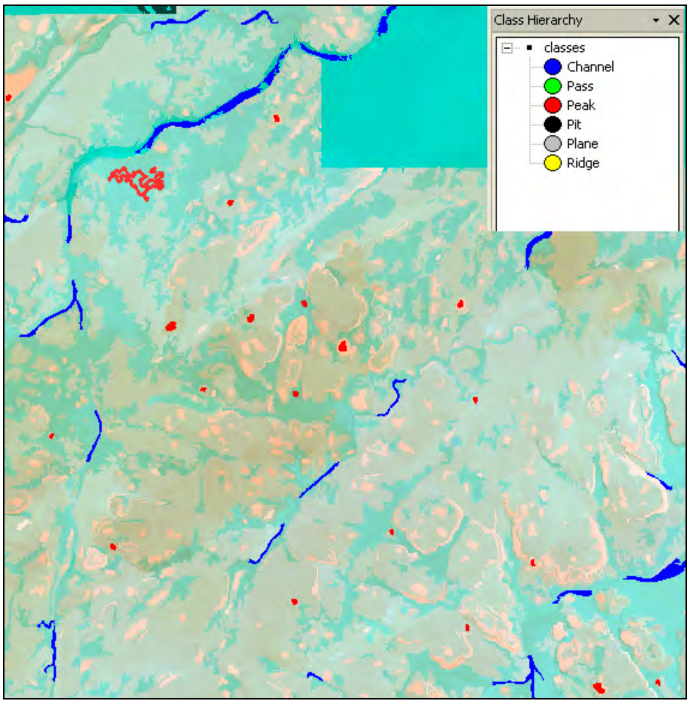

Figure 4: Supervised classification of channels and peaks using eCognition software.

5. DISCUSSION

The objective of the work reported here is to provide evidence that software exists that is capable of mapping landform patterns and landform elements at the land subsystem level in areas where the land surface is currently only mapped at a land system level. This research aims to significantly increase available land condition data in the Ord River Catchment and to devise a method that can be expanded to other areas of the pastoral rangelands.

Providing land subsystem level data for the PLAGA project will increase the quality and quantity of data for land condition assessment. Early warnings of land degradation especially at higher resolution could be used to trigger land management response, such as lowering stock numbers or complete de-stocking, to avoid long-term damage to the pastoral rangelands (Robinson, pers. comm., 2010). Increased quality and quantity of data incorporated into PLAGA will also improve the identification of areas that have recovered from previously ‘poor’ states that can be used, for example, to gauge the outcomes of such land management responses (Robinson, pers. comm., 2010).

The results have shown that LandSerf provides a good basis classification however limitations of LandSerf were discovered in that the user is unable to alter curvature and slope tolerances or change the processing model. These limitations not only prompt further investigations into other techniques and software types but also identify likely sources of error.

Object-based image analysis methods allow integration of existing remote sensing techniques and allow incorporation of classification practices that increase the power of semi-automated classification (Lang 2008). ECognition is powerful OBIA software that produced results that are promising for landform element classification in this research. Error and uncertainties are still factors that will need to be addressed with further application of this software.

6. CONCLUSION

This ongoing research will continue in order to refine suitable techniques and results for landform classification within the Western Australian pastoral rangelands. Accuracy was a problem in the past that inhibited the use of semi-automated to automated feature extraction from digital information to be used in land condition monitoring programs. This has led to continual challenges in monitoring remote areas to a high degree of certainty to support policy, planning and management for sustainability.

Both LandSerf and eCognition have proved capable of producing landform data. The challenge now is to perfect this data and simplify the methods so that they can be applied to other pastoral rangelands with varied terrain. By achieving landform classification in remote areas it would then be possible to extrapolate this information to soil types and vegetation types.

Understanding the landforms, soils and vegetation ultimately will lead to better monitoring of pasture degradation with more feasible results relying less on field-based surveys.

7. REFERENCES

[1] McKenzie, N. J.: Australian soils and landscapes : an illustrated compendium. Collingwood, Vic.: CSIRO Publishing (2004).

[2] Robinson, T.: Remote Sensing-Based Rangeland Condition Monitoring: Past, Present and Potentials. In *The PLAGA Project*. Perth, WA. Curtin University of Technology (2009).

[3] Department of Regional Development and the North West, and Kimberley Regional Development Advisory Committee (WA).: *Kimberley regional profile Western Australia*. Kununurra, W.A (1986).

[4] Speight, J. G.: Landforms. In Australian Soil and Land Survey Field Handbook, ed. The National Committee on Soil and Terrain, 15-72. Canberra, Australia: CSIRO Publishing (2009).

[5] Schoknecht, N.: Land unit mapping for the Ord and Keep River catchments, edited by Department of Agriculture. Perth, WA. Department of Agriculture (2003).

[6] Wood, J.: The LandSerf Manual. *User Guide for LandSerf 2.3.1* (2009).

[7] United States Geological Survey. EarthExplorer. http://edcsns17.cr.usgs.gov/EarthExplorer/ (accessed Jan 2011).

[8] Lang, S. Object-based image analysis for remote sensing applications: modeling reality - dealing with complexity. In *Object-Based Image Analysis. Spatial concepts for knowledge-driven remote sensing applications*. ed. T. Blaschke, Lang, S. and Hay, G.J., 3-29. Heidelberg: Springer (2008).

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

VEGETATION MONITORING OF LAKE TOOLIBIN USING LANDSAT SATELLITE IMAGERY: ANALYSIS AND IMPLEMENTATION

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1. ABSTRACT

The Landsat series of satellites have an extensive archive, with data available from 1972. Spectral band combinations or indices can be derived from the imagery to provide quantitative information regarding vegetation cover change during this period [1]. A vegetation monitoring program of Toolibin Lake and reserves was commenced in 1977 and continues to this day. It consists of 35 permanent 20m by 20m plots which have been surveyed and described at regular intervals.

The aim of this study was to firstly, identify the most appropriate vegetation index to use on the lake bed of Lake Toolibin, then, derive an algorithm to convert satellite data to projected foliage cover (PFC), and finally, to assess the feasibility of integrating time series PFC values into the current monitoring program.

A Canonical Variate Analysis (CVA) demonstrated that the single Landsat band 5 was optimal to describe vegetation density in the Toolibin Lake bed. Field derived PFC estimates had a high correlation ($r^2 = 0.832$) with Landsat band 5 digital counts. Temporal changes to PFC values correlated with changes reported by the Lake Toolibin monitoring program. The integration of satellite derived vegetation cover assessments into the current program would provide a useful and cost effective measure, which could be used in conjunction with field measures, to assess plot condition. The use of satellite imagery also allows for vegetation assessments to be extrapolated across the entire reserve and not restricted to a number of points.

2. INTRODUCTION

Lake Toolibin is an ephemeral lake in the agricultural zone of Western Australia. It is a Ramsar listed wetland and when inundated, is the richest breeding habitat for waterbirds in southwest Australia [2]. Since the mid 1980s the vegetation of Lake Toolibin has been effected by salinisation and waterlogging. Actions have been taken to manage catchment hydrology in order to conserve vegetation communities present and halt any decline [3]. A vegetation monitoring program of Toolibin Lake and Reserves was commenced in 1977 and continues to this day. The program was implemented as part of Lake Toolibin Recovery Plan. It consists of 35 permanent 20 m by 20 m plots which have been surveyed at regular intervals. Data collected includes counts of live tree numbers and species along with tree health scores and soil salinity data [4] .

In Australia, Landsat satellite imagery has been used for mapping and monitoring woody perennial vegetation [5, 6]. The Landsat series of satellites has and extensive archive, with data available from 1972. Vegetation indices can be derived from a combination of Landsat spectral bands to provide quantitative information regarding vegetation cover [7]. In the southwest of Western Australia the Land Monitor Project utilises a vegetation cover index based on Landsat bands 3 and 5 [1]. Consistent image processing techniques allow direct comparison of index values over time [1, 5] and have been implemented in Western Australia (WA) by the Land Monitor Project. Consistently processed Landsat data of the south west of WA, captured at one and two year intervals, is available from the Land Monitor Project [8].

The Land Monitor Project vegetation index, utilising Landsat bands 3 and 5, has proved to be a suitable "generic" index, which has been used to map and monitor vegetation across the southwest. However, statistical methods can be used to identify band combinations which may be more sensitive to vegetation variability in specific areas. The Canonical Variate Analysis (CVA) is one such technique. CVA can be used to summarise the separation between training sites using the 6 band Landsat data and was used in by the Land Monitor Project [9]. Routines to identify the discriminating bands and band combinations have been developed [10]. Often the greatest spectral separation between sites is located in the first and second canonical variate directions, this allows the dimensionality of the data to be reduced. To examine the maximum variation in cover, contrasted directed CVA, using a set of dense and sparse training sites, can be used to establish the band or band combination that best represents the variation. This band or band combination can then form the basis of a vegetation index used to map and monitor cover changes.

Identifying surrogates, which correlate with vegetation indices and provide information to which vegetation condition can be assessed, is a key component when using satellite imagery in environmental studies. A number of field based measures can be used including overall condition [11, 12], vegetation cover [13] and Projected Foliage Cover (PFC) [14]. Field techniques to measure PFC include visual estimation from templates, fish-eye photography and vertical digital photography. PFC derived from vertical digital photography has been identified as a simple and accurate ground-based method for estimating cover [15]. PFC can also be calculated from a combination of canopy cover, derived from aerial photography and foliage cover, estimated from templates in the field [16].

The aim of this study was to:

1. identify the most appropriate vegetation index to use on the lake bed of Lake Toolibin;
2. derive an algorithm to convert satellite data to projected foliage cover; and
3. assess the feasibility of integrating time series projected foliage cover values into the current Lake Toolibin vegetation monitoring program.

This report includes, and adds to, work carried out by Zdunic [17].

3. METHODS

3.1. Index selection

A canonical variate analysis (CVA) was used to determine which Landsat band or band combinations were the most suitable to assess vegetation cover across Lake Toolibin. The CVA was carried out using software tools RBSTCV (Robust Canonical Variate Analysis) and SELECT (Channel Selection in Canonical Variate Analysis) developed by the CSIRO. Pixel values from 30 calibration sites within the Lake Toolibin reserve were analysed using RBSTCV. All sites were at least one hectare in size with a homogenous spatial distribution of vegetation cover (assessed from aerial photography). The calibration sites covered a range of dense and sparsely vegetated areas. Each site was checked to ensure pixel values had a low standard deviation. A suite of calibration sites with the above criteria enables robust examination of how the spectral response in Landsat imagery responds to changes in vegetation density in a given area.

The RBSTCV analysis of the calibration sites produced plots displaying the contrast between low and high density sites. SELECT was then used to determine which bands contribute most to this contrast. PFC values were regressed against Landsat band 5 digital counts, the density index ((band 3 + band 5)/2) and the normalised difference vegetation index (NDVI).

3.2. Collection of Field Data to derive Foliage Cover

On 6 and 7 May 2010, 12 of the 30 calibration sites were surveyed. Information collected at each site included a site description and site estimates of vegetation cover. The canopy density of 3 trees within each site was estimated using templates [18] (Figure 1). Vertical digital photographs of the canopy were taken from 4 points and later analysed using ERMapper to calculate canopy density. These estimates were averaged per site. Canopy cover for each site was estimated using templates and aerial photography captured in 2005 (Figure 2).

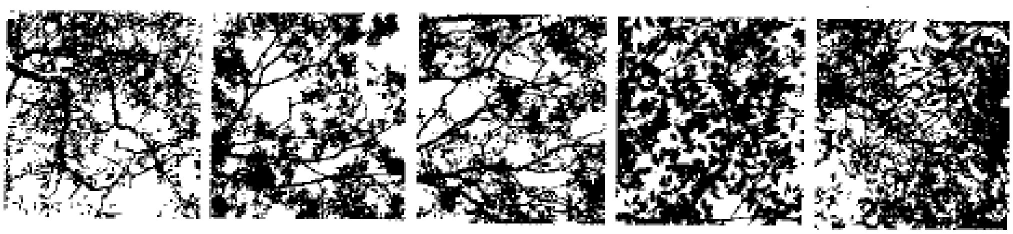

Figure 1: A subset of canopy density estimate templates [18]. The templates range from 45% (left) to 65% (right).

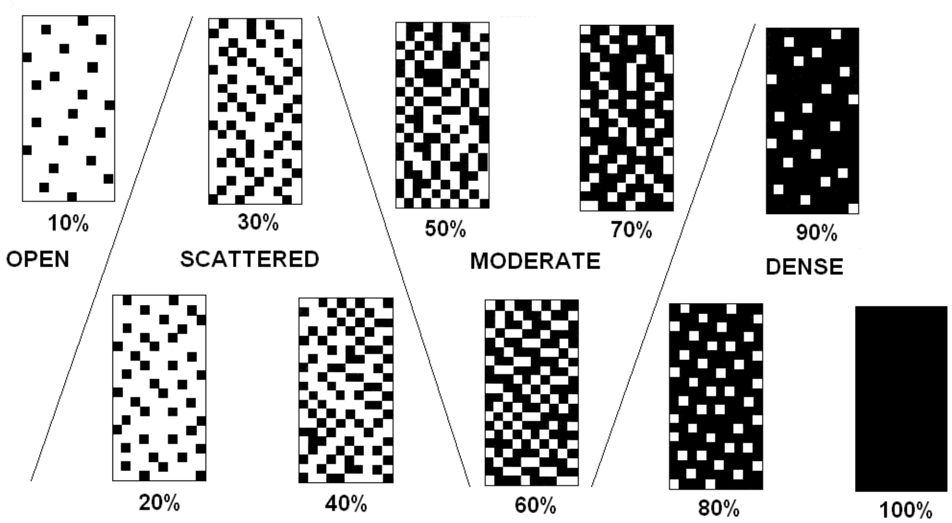

Figure 2: Templates used to estimate canopy cover from aerial photography [19].

Projected foliage cover (PFC) was calculated for each site by multiplying canopy cover by canopy density values then dividing the result by 100. PFC was calculated using canopy density estimates from templates and vertical digital photography. PFC derived from field estimates and aerial photograph interpretation for each calibration site were regressed against digital counts from band 5 from 2010 Landsat imagery. A trend line was fitted to the data. The formula from this trend line was applied to a sequence of band 5 images from 1990 to 2010 (Table 1). The imagery was provided by the Land Monitor Project and has been rectified and calibrated [20].

year	capture date	year	capture date	year	capture date
1990	2/02/1990	2000	6/02/2000	2006	2/03/2006
1992	7/01/1992	2002	11/02/2002	2007	16/01/2007
1994	28/01/1994	2003	26/11/2002	2008	27/01/2008, 11/01/2008
1996	3/02/1996	2004	23/12/2003	2009	5/01/2009
1998	7/01/1998	2005	10/01/2005	2010	24/01/2010

Table 1: The date of capture and image year for Landsat imagery used in the time series.

3.3. Integration of PFC within vegetation monitoring

Coordinates for monitoring plots from the Vegetation Monitoring of Toolibin Lake and Reserves program were converted from points to 50 m by 50 m polygons. This ensured that four pixels were sampled at each plot. The position of these polygons was manually adjusted to ensure they appeared to cover a patch of “representative” vegetation (i.e. did not cover roads). Average PFC values from 1990 to 2010 were then extracted from the Landsat time series and graphed against live tree count data for the same period. Years which caused spikes in the PFC values were considered to be affected by surface water and were removed.

A vegetation trend image was derived using linear and polynomial trends from all images in the sequence. This was done using CSIRO software, following standard methods [7].

4. RESULTS

4.1. Index Selection and projected foliage cover calculations

Band 5 had the highest contribution to the canonical vector that describes the variability of cover (-0.21379) and described 98.2% of the contrast directed CVA. The strong relationship between Band 5 and PFC in Lake Toolibin was confirmed by regressing commonly used vegetation indices including normalised difference vegetation index (NDVI) and the density index (DI) ((band 3 + band 5)/2, used in the Land Monitor Project (Caccetta et al, 2000)), with PFC (Figure 3). The relationship between PFC, derived from field measurements and aerial photograph interpretation, and digital counts from band 5 from 2010 Landsat imagery was marginally stronger than that of the density index (r^2 = 0.832), with NDVI considerably lower (r^2 = 0.6553).

PFC calculations using templates to estimate canopy density had a stronger relationship (r^2 =0.832) with Landsat band 5 than PFC calculated using processed vertical digital photographs (r^2 =0.8128).

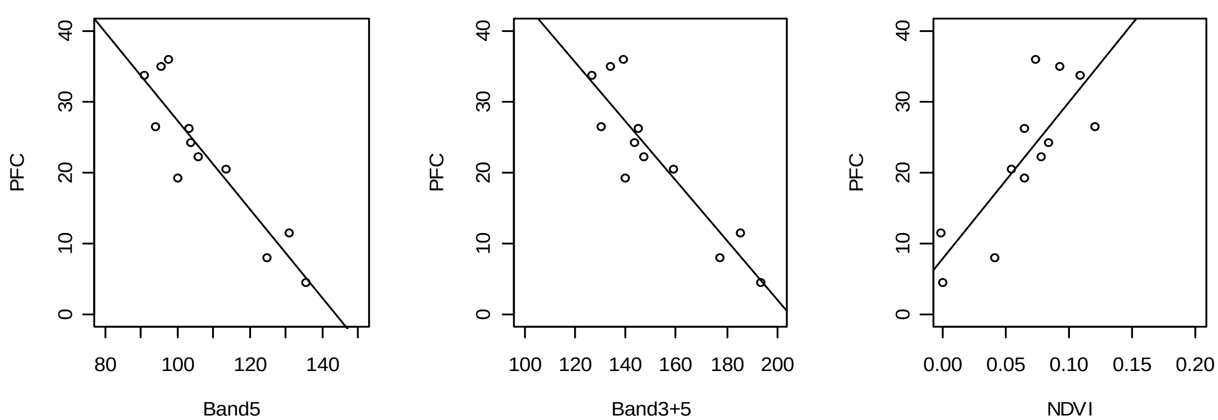

Figure 3: Calibration plot measures of PFC regressed against digital counts from band 5 (r^2 =0.832), band 3 + band 5 (r^2 = 0.8135) and NDVI (r^2 = 0.6553) from 2010 Landsat imagery.

4.2. Integration of PFC within vegetation monitoring

Time series for PFC and “live tree count” from monitoring plots 4 and 33 are graphed with and without anomalies removed (Figure 4 and Figure 5). In both plots the declining trend in tree count number is matched with the decline in PFC. The steady decline in PFC in both plots is evident once anomalies have been removed.

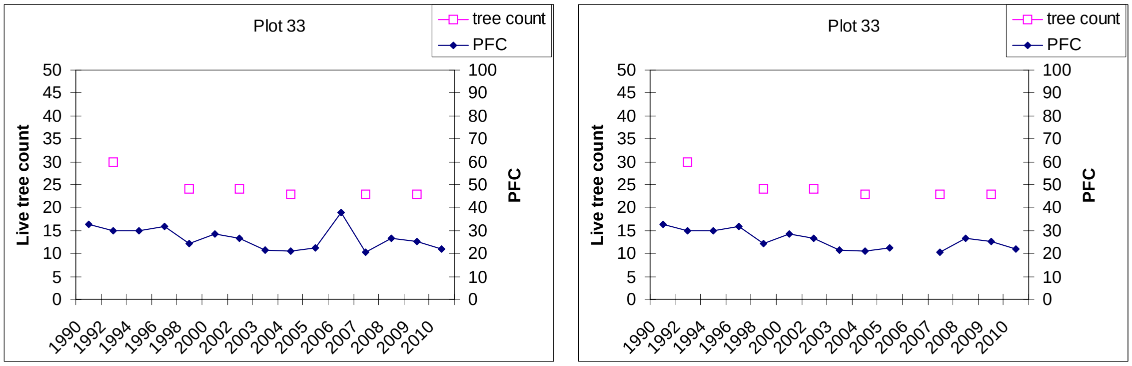

Figure 4: PFC and live tree count data from 1990 to 2010 for plot 33, without (left) and with (right) anomalies removed.

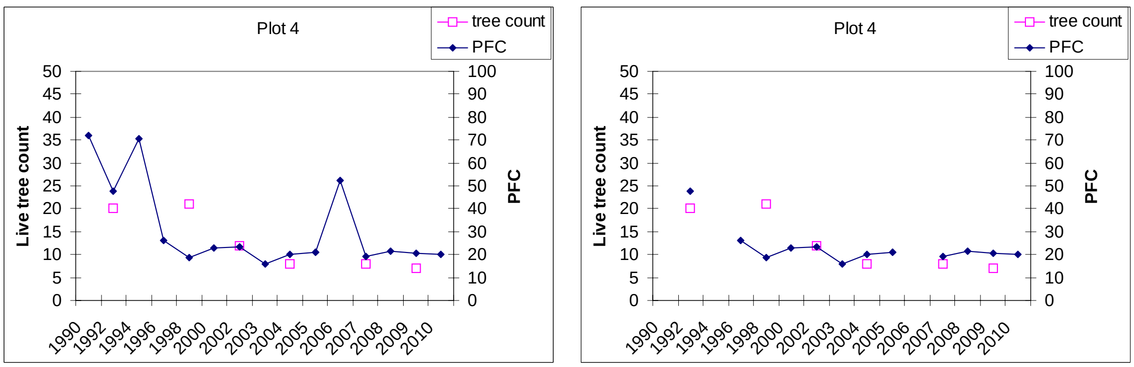

Figure 5: PFC and live tree count data from 1990 to 2010 for plot 4, without (left) and with (right) anomalies removed.

4.3. PFC trend image

The PFC images created for each year in the 1990 to 2010 time series were used to create a trend image. The trend image provides a simplified spatial representation of areas of PFC change over the lake bed (Figure 6). The image displays areas with declining (red), increasing (blue), fluctuating (green) and stable (black) PFC values and areas without vegetation cover (grey). The value of this type of analysis is that it allows the spatial variability of change within an area to be analysed.

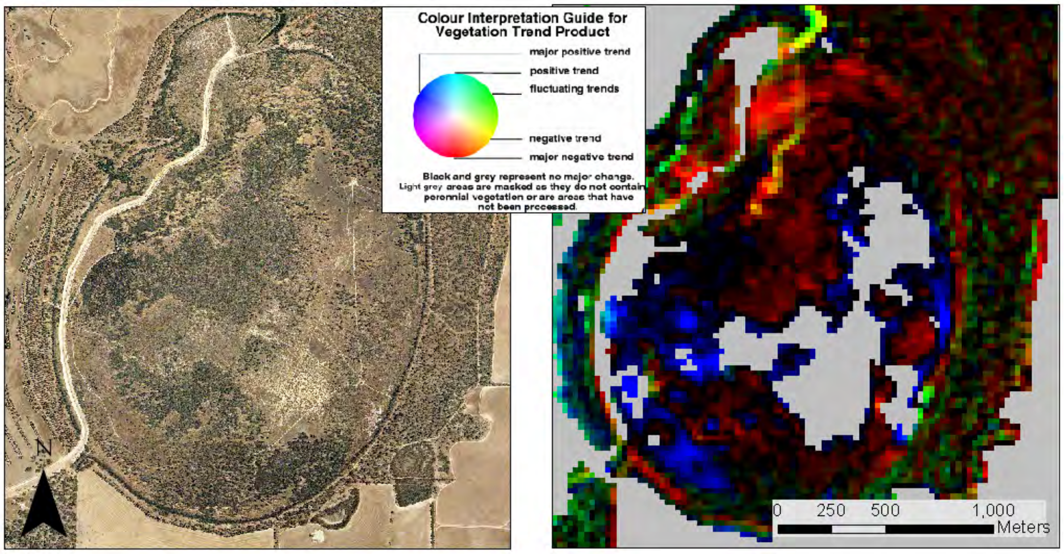

Figure 6: An aerial photograph (captured 2005) and trend image of Lake Toolibin. The trend image was derived using data from 1990 to 2010 and includes a colour wheel legend. The trend image displays areas with declining (red), increasing (blue), fluctuating (green) and stable (black) PFC values.

5. DISCUSSION

5.1. Index selection and PFC

The CVA proved to be an effective tool to identify the optimal spectral information to differentiate changes in vegetation density in the Lake Toolibin lake bed. The CVA identified band 5 as the most effective Landsat band. This was confirmed by the strong relationship between band 5 PFC values.

PFC derived from templates received higher correlations with the band 5 index than PFC derived from digital photograph interpretation. This may be in part due to difficulties in interpreting photographs taken at different times of the day. Glare from the sun often made photographs taken between approximately 11 am and 2 pm difficult to interpret. Avoiding data collection during this time period would be ideal but impractical, as this would severely limit the amount of data collectable. The considerable processing time required to analyse photographs also make the use of templates more appealing and practical. Another confounding element when deriving PFC was the use of canopy cover measurements from 2005 aerial photography with field measurements taken in 2010. The 5 year difference in date is not ideal, but is a practical limitation as 2005 imagery was the most resent capture freely available. The extent to which this impacted results is unclear.

5.2. Integration of PFC within vegetation monitoring

Time series PFC values within the monitoring plots analysed in this study appeared to follow changes at the sites reported in the monitoring program. However, PFC did not correlate with the live tree count data in all 35 plots. It may be the case that time series PFC graphs need to be viewed in context of all changes occurring at the site and will not necessarily correlate with other measured parameters. Factors affecting the accuracy of monitoring plot PFC graphs are the size of the monitoring plots relative to Landsat pixel size. The 20 m by 20 m plots used in the monitoring program are smaller then the 25 m by 25 m pixel size of the Landsat imagery. Sampling a single pixel in a time series of Landsat imagery is problematic as small (10 to 15 m) shifts in the area of ground a pixel represents can cause annual fluctuations in the PFC values. This effect can be reduced by selecting a 50 m by 50 m plot which would cover 4 pixels, however 75 by 75 m plots would be more robust. In either case the areas used must be individually assessed to ensure they are representative of the area covered by the monitoring plot. The output must also be checked to ensure that “sensible” results are returned (that values do not fluctuate dramatically from year to year).

The Landsat images used in this study were capture in summer (generally December to February) to minimise seasonal variations caused by the emergence of annuals. The presence of surface water, or even variations in soil moisture, will also significantly reduce reflectance in band 5 and therefore increase estimated PFC values, causing them to appear artificially high. Such anomalies can be identified in time series graphs and removed from the sequence. If Landsat imagery is to be relied upon as a monitoring tool, a filter could be incorporated into image processing to remove areas of suspected high soil moisture content. Alternately, images (such as the 2006 scene which was captured after a large rainfall even) could be substituted with a different scene which could be purchased for a moderate cost. In this study images which contain surface water are considered anomalies and removed from the analysis. However, these anomalies may provide useful information for each plot. Counts of the number of times each monitoring plot was inundated in summer may be a useful statistic and could easily be generated.

The spatial application of satellite imagery makes assessing vegetation change across wide areas feasible. Trend images can be used to summarise change across the reserve and to identify areas of cover decline and recovery which may require further investigation but are not sampled by permanent plots. The incorporation of trend image analysis into the Lake Toolibin Monitoring Plan would help build a more comprehensive view of vegetation change across the entire Lake Toolibin reserve.

6. CONCLUSION

The PFC measures derived from Landsat satellite imagery could be added to the range of parameters collected in the current monitoring program. Temporal changes to PFC values from the sites analysed in this study correlated with changes reported at each of the sites by the Lake Toolibin Monitoring Program. The use of satellite derived PFC measures allows changes in cover across the entire Toolibin Lake and Reserves to be assessed and is not restricted to a small number of sample points. When analysing PFC values for the current monitoring plots the greatest source of error appears to be seasonal fluctuation caused by surface water or damp soil in the lake bed. Ensuring that the geographical positioning of polygons used to sample plot PFC values are accurate and representative will also reduce error in time series graphs. The integration of satellite derived vegetation cover assessments into the current program would provide a useful and cost effective measure, which could be used in conjunction with field measures, to assess plot condition. The use of satellite imagery also allows for vegetation assessments to be extrapolated across the entire reserve and not restricted to a number of points.

7. REFERENCES

[1] Caccetta, P., Campbell, N., Evans, F., Furby, S., Kiiveri, H.,Wallace, J., *Mapping and monitoring land use and condition change in the South-West of Western Australia using remote sensing and other data*, in *Proceedings of the Europa 2000 Conference*. 2000: Barcelona.

[2] Jones, S., Lacey, P.,Walshe, T.: A dynamic hydrological Monte Carlo simulation model to inform decision-making at Lake Toolibin, Western Australia, *Journal of Environmental Management*. Vol. 90: pp. 1761-1769, (2009).

[3] Wallace, K., Beecham, B.,Bone, B., *Managing Natural Biodiversity in the Western Australian Wheatbelt*. 2003: Perth.

[4] Ecoscape, *Vegetation Monitoring of Toolibin Lake and Reserves*. 2007, Ecoscape (Australia) Pty Ltd: North Fremantle.

[5] Caccetta, P., Furby, S., O'Connell, J., Wallace, J.,Wu, X., *Continental Monitoring: 34 Years of Land Cover Change Using Landsat Imagery*, in *32nd International Symposium on Remote Sensing of Environment*. 2007: San Jose, Costa Rica.

[6] Kuhnell, C.A., Goulevitch, B.M., Danaher, T.J.,Harris, D.P., *Mapping Woody Vegetation Cover over the State of Queensland using Landsat TM Imagery*, in *Proceedings 9th Australasian Remote Sensing and Photogrammetry Conference*. 1998: Sydney, Australia.

[7] Furby, S., Zhu, M., Wu, X.,Wallace, J.F., *Vegetation Trends 1990-2008: South West Agricultural Region of Western Australia: 2008 Update of the Land Monitor II Project: Product #3 – Vegetation Trends*. 2008, CSIRO Mathematical and Information Sciences: Perth, Australia.

[8] Furby, S., *Land Monitor Vegetation Image Date Summary: Land Monitor II 2009 Update*. 2009, CSIRO Mathematical and Information Sciences: Perth, Western Australia.

[9] Caccetta, P., Alan, A., Watson I *The Land Monitor Project*, in *Proceedings of the Tenth Australian Remote Sensing Conference.* 2000: Adelaide, Australia

[10] Campbell, N., *Some aspects of allocation and discrimination*, in *Multispectral Statistical Methods in Physical Anthropology*, G. van Vark,W. Howells, Editors. 1984: Reidel, Amsterdam.

[11] Wallace, J., Behn, G.,Furby, S.: Vegetation condition assessment and monitoring from sequences of satellite imagery, *Ecological Management & Restoration*. Vol. 7: pp. S31-S36, (2006).

[12] Robinson, T., Novelly, P., Watson, I., Corner, R., Thomas, P., Schut, T., Jansen, S.,Shepherd, D., *Towards an approach for Remote Sensing-Based Rangeland Condition Assessment in North Western Australia*, in *Surveying & Spatial Sciences Institute Biennial International Conference*. 2009: Adelaide.

[13] Pickup, G., Chewings, V.H.,Nelson, D.J.: Estimating changes in vegetation cover over time in arid rangelands using landsat MSS data, *Remote Sensing of Environment*. Vol. 43: pp. 243-263, (1993).

[14] Kinloch, J., Zdunic, K., Behn, G.,Wilson, B., *Monitoring Vegetation Condition in the Banksia Woodland of the Gnangara Mound: The Role of Remote Sensing Tools*, G.S.S. Taskforce, Editor. 2009, Department of Environment and Conservation.

[15] Macfarlane, C.: Photographic estimation of overstorey and understorey cover, *unpublished*. (unpublished).

[16] Behn, G., McKinnell, F., Caccetta, P.,Vernes, T.: Mapping forest cover, Kimberley Region of Western Australia, *Australian Forestry*. Vol. 64: pp. 80 - 87, (2000).

[17] Zdunic, K., *Lake Toolibin Vegetation and Landsat TM Analysis*. 2010, Department of Environment and Conservation: Perth.

[18] Hnatiuk, R.J., Thackway, R.,Walker, J., *Vegetation*, in *Australian soil and land survey field handbook*. 2009, CSIRO Publishing: Melbourne.

[19] Bureau, F.a.T., *Density Scale*. 1950. p. Guide for estimating degree of forest cover.

[20] Furby, S., *Land Monitor Vegetation Image Date Summary*. 2010, CSIRO Mathematical and Information Sciences.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

DYNAMIC VISUALISATION OF TOURISM IMPACT IN THE NINGALOO REGION

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ABSTRACT:
The Ningaloo region in the northwest of Western Australia is a popular tourist destination with its primary attraction being its unique and fragile environment. While the environmental impacts of tourism are concerning, they need to be considered alongside tourism growth, since it is the largest regional economic activity. To explore impacts of tourism, complex models have been constructed that include drivers, such as fuel costs and a resources boom, and how these can affect local communities, the economy and the environment, including the number of tourists, required resident numbers, accommodation, fish stocks and jobs. Such models usually produce tables and graphs that often fail to communicate messages to a broad audience. This paper explores visualisation techniques targeted to show impact in a number of visually pleasing ways using a digital earth environment. Changes for specific sub regions for beach visitors, houses and caravans can be shown both spatially and temporally. The results of tourism models are processed on the fly as required by the user and displayed using Google Earth embedded in web pages. Techniques used include 3D models, images, icons and pop up graphs.

1. INTRODUCTION

Digital Earth initiatives [2] visualise large diverse data sets in a three dimensional globe representation. To date the focus has been on the display of data for everyone including the general public. What is now required is to use the digital earth to explore simulations and predictions for decision making and communication involving all stakeholders. This paper explores dynamic cartographic and visualisation in a digital earth to show tourism impact in a number of visually pleasing ways that address the requirements of different user groups and issues. This uses a model of tourism development for the Ningaloo Coast region in the northwest of Western Australia.

As a fragile environment that relies on nature-based tourism as its primary economic driver, the Ningaloo Coast in the northwest of Western Australia needs to balance tourism development with protection of its environmental attractions, in particular a highly accessible fringing coral reef that extends for over 300 kilometres along its coastline. Conflicts over land use in particular are common in the region, and management changes have been strongly resisted [3, 4]. The Ningaloo Destination Model (NDM) is a scenario planning tool that assesses the economic, tourism, social and environmental impacts of different development strategies. Despite having the capacity to address difficult dilemmas in the region, communicating modelling results to a broad audience has been difficult. This paper discusses the technical issues that need to be addressed when using a digital earth to present modelling results. In particular, the use of 3D models, images, icons and pop up graphs in a dynamic framework to make different types of data apparent and help users to focus on strategic learning (the primary goal of model use) rather than a specific graphical representation.

2. BACKGROUND

Communicating the impacts of tourism is difficult because of how tourism functions as a set of activities across a number of fields. Tourism is driven by the activities and expenditure of visitors from outside a region, state or country. These visitors often consume the same services and buy the same products as locals, such as shopping, fishing and generating waste, as well as buying leisure activities such as tours and tourist accommodation. Tourists move on, are quickly replaced by new visitors and so are rarely aware of their impacts. Tourism workers are more aware, particularly of positive impacts such as how expenditure in restaurants and supermarkets benefits a community. Other organisations that provide services to tourists do not perceive the benefits, do not see themselves as, or connected to, tourism organisations [5]. This can include protected area managers and local government who manage the negative impacts of tourism, but receive little direct financial compensation from tourists. Although tourism is currently the largest economic activity and the primary generator of environmental and social impacts in the Ningaloo Coast region, there is little understanding about tourism's influence on the socio-ecological system, and many grey areas associated with tourism impacts and management. This underlies the importance of modelling as a method of communicating the impacts of tourism, and the need for clear and engaging methods of presenting scenarios and predictions that have the capacity to reach a general audience.

The Ningaloo Reef is the largest fringing coral reef in Australia stretching over 300km along the remote northwest coast between the Carnarvon and Exmouth townships (Figure 1). The exceptional conservation values of the region include marine and terrestrial flora and fauna, karst formations and subterranean fauna, and remoteness values. This coastal region is sparsely populated and its approximately 8000 residents live in the towns of Carnarvon (71%), Exmouth (27%) and Coral Bay (2%). The region's economy is based on tourism, fishing, mining, horticulture and livestock, while nature-based and wilderness tourism is the main source of income in Exmouth and Coral Bay, and is marketed nationally and internationally as a premier tourism destination [6]. Tourism expenditure for the year ending September 2008 was estimated to be $127 million, with 179,352 visitors staying for an average of 9.92 nights [7]. The primary attraction of the region is the Cape Range National Park and the Ningaloo Marine Park, which Western Australia's Department of Environment and Conservation labelled the state's 'premier marine conservation icon' [1]. Land use conflicts are frequent, and the region has seen hotly debated disputes over resort developments, marine sanctuaries, and World Heritage nomination [8].

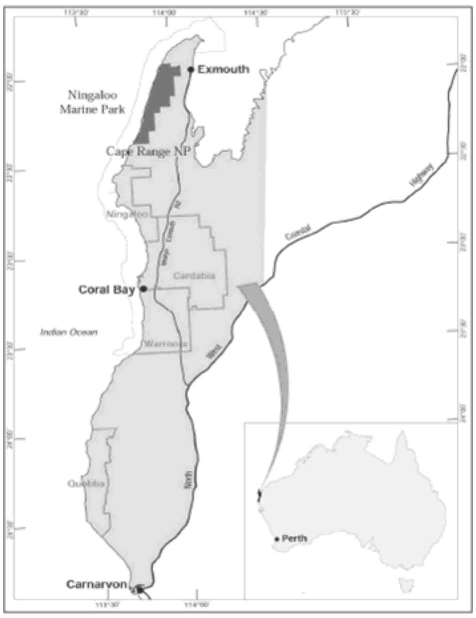

Figure 1: Map of the Ningaloo Coast Region. Source: [1]

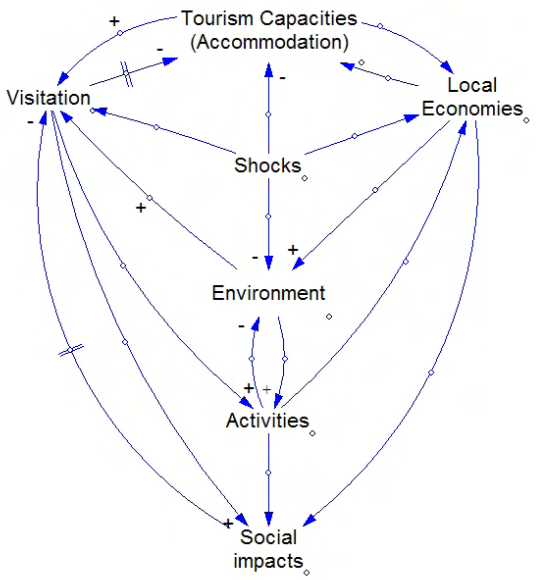

Figure 2: Conceptual diagram of the tourism model showing causal links between different spheres

The Ningaloo Destination Model (NDM) project addressed land use planning issues by capturing the complexity of the tourism system. The NDM is a numerical model built using a system dynamics approach in the Vensim® modelling software.[1] The model integrates primary and secondary data and addresses feedback loops and delays, to capture the behaviour of the tourism system (Figure 2). The NDM was calibrated with an ecological model of the region developed by a sister project[2] to incorporate ecological indicators alongside the economic, social, tourism and resource use indicators used in the model. The model used statistics from numerous agencies and collected primary data including 1574 tourism surveys and 287 resident surveys. The outputs of the model were divided into four categories: tourism, economic, social and environmental. Simulations ran for thirty years from 2007 on an annual time scale.

The development of the NDM had a strong emphasis on engagement [9-12], following modelling philosophies that emphasise user-centred methods of model development [13, 14]. Model data was presented in fifteen out of nineteen stakeholder forums as well as at meetings with individual stakeholders. Line graphs representing change in a variable over time was confusing for participants without a strong statistical background. Snapshots of change at particular points across time in bar charts were much better received. However, participants in forums who did not work in positions where graphs were often used struggled to read and interpret the outputs. Temporal data was difficult to communicate as its complexity results in graphs with many lines that caused confusion. The goal was to communicate to a general audience the potential impacts of different development strategies, and it became clear that graphs were not an effective method for communicating modelling research to a general audience.

Models are best used to compare the outcomes of different strategies based on the best available data. Graphs are suitable to because they provide a highly generalised set of results. Once the specifics of, for instance, where a hotel is to be built and its size, becomes part of the output, there is a danger that it could be viewed as a likely outcome and the results accepted or rejected. Results require a degree of generality in order to focus users on strategic decision making, rather than a specific outcome that could be highly unlikely. Digital Earth representations of modelling results need to be both engaging for users in their depiction of possible scenarios, but also to capture the uncertainty. This is particularly important given residents' personal investment in where they live and their strong response to potential changes to activities and locations they value.

Graphs are easy to compare to each other for small numbers of data sets. This is important in modelling, where the trade-off between different scenarios is a key to developing outcomes that all groups can accept. However, they do not cope well for complex datasets as comparisons across a number of indicators are difficult. Digital earth representations were explored to encourage and facilitate comparisons between scenarios, as well as connecting a variety of different indicators within a specific scenario. Datasets of indicators were generated over 30 years from 2007 from the NDM for economic, tourism, social and environmental areas: visitor numbers per night, resident numbers and housing, expenditure, accommodation development, water use, electricity use, snorkelling, beach use, fishing from boats, fishing from shore, sightseeing, and fish stocks. The geographic placement of activities was via survey data and interviews with researchers familiar with the region, and through the town structure plans for Exmouth and Carnarvon, the current regional plan [15], the proposed plans for tourism developments, and interviews with developers with interests in the region.

3. VISUALISATION TECHNIQUES IN DIGITAL EARTH ENVIRONMENTS

Many of the tourism model outputs relate to regions, such as housing in a future residential area or visitors to a beach. The regional plans for Ningaloo have a number of relevant polygons such as for future residential and hotel development. However there are none for beach, snorkelling and other regions. These were generated interactively using Google Earth and ArcGIS from knowledge of the

[1] http://www.vensim.com/
[2] The developer of the ecological model was Beth Fulton in the CSIRO's Research and Atmospheric Division. For more information on the models, see [9, 11].

area and recent research into human use [16]. There was some subjective assessment of the extent of a beach because of ambiguities in the borders with the ocean and surrounding bush. Each polygon had a border colour and thickness, and a fill colour. For some regions, specified colours were copied from town plans. To display activity, the fill colour opacity was changed as a function of the tourism model. The border colour represented the maximum value of 100% and the fill colour opacity normalised to range between 0% (no activity) and 100% (maximum activity) enabling the user to gauge the level of activity by comparison with the border colour. A 3D method was also explored for future residential and future hotel developments. Each polygon had a height dimension added such that the height of the 3D shape represented the number of houses hotels etc. The 3D border or wireframe was used to indicate the maximum height. Polygons were not useful for beaches because they were long and thin becoming visible only when zooming in on a specific beach or beaches. Instead a different approach was investigated based on icons. In Google Earth, icons stay at a constant size whatever the viewing distance from the earth and hence are always visible enabling the user to see where activity is occurring and where they may want to focus their attention. Varying the size of icons enabled changes in beach, snorkelling, fishing and surfing activity to be easily viewed at multiple scales.

2D images and 3D models of various objects were investigated to generate more realistic visualisations. An example would be a new housing estate in which a region would be populated by a number of houses arranged in some fashion to produce a realistic view. Another example would be people on a beach with models of humans appropriately attired along with beach umbrellas and other paraphernalia. Both 2D images and 3D models were investigated with 3D models having the advantage of realism whereas 2D images are less expensive in terms of bandwidth and computation. Each 3D model of a house typical of the region was generated as a kmz file (a compressed form of kml[3] file containing a number of different files in the case of a 3D model). Each kmz file consists of a kml file: that references a dae collada[4] file for the geometry of the model, and png images for the texture of the various surfaces of the houses (roof, walls). The kmz file typically describes one house but could be modified to contain the location and orientation of a number of identical houses using the same geometry and image files. 3D models have a high quality appearance meaning they looked out of place superimposed on the background satellite imagery. Experiments with reasonably complex house models also revealed that current hardware had rendering problems with too many models. To explore the usefulness of 2D images, images were generated from top down views of the 3D house models but these were also of high quality and looked out of place in the landscape. Blurring the images to soften the hard edges resulted in an improved appearance. The best approach was to extract images of actual houses from the satellite imagery allowing houses of a similar style and appearance to be added. To further blend the house images into the landscape, the transparency of the images was varied from full opacity at the centre gradually becoming fully transparent towards the edges. The number of objects to be added to the visualisation was determined from the tourism model, with the positions determined using one of two techniques: (1) random placement of the objects, and (2) placement on a grid. Neither of the two methods is completely satisfactory but allowed some idea of growth to be visualised. Random placement required collision detection to prevent houses overlapping whereas placement on a grid avoids the collision detection but results in a less realistic pattern.

When a tourism activity affects a number of regions, then other factors need to be considered. For example, in Exmouth there are three regions that are specified for future housing with no preference stated for which regions to occupy first. The preferred solution was for the regions to be occupied in some predefined sequence. For houses it was by distance to the town centre. For beach activity e.g. for the Cape Range National Park, Turquoise Bay is the favoured spot and it can be expected that visitors would go there before trying other beaches. Hence beaches were ranked in distance from Turquoise Bay.

All the techniques described above were used to give an impression of growth and change for the tourism models. To add more information from the model, mousing over an icon reveals an alternative icon that represents a graph of the model data, generated using the jgraph graphics library[5].

[3] http://code.google.com/apis/kml/documentation/
[4] http://collada.org
[5] http://jgraph.com

The techniques described above were implemented in a web page environment using the Google Earth API plugin allowing changes to the various tourism models, simplifying the application and enabling the guidance of the user. The LAMP architecture (Linux, Apache, MySQL and PHP) was used with the AJAX framework (Asynchronous Javascript And Xml). Figure 3 shows the architecture, flow and storage of information and languages used. In the main, html and javascript ran on the client to access the Google Earth API and php was used on the server to take instructions from the client and to generate the appropriate kml and kmz files for uploading to the client for display using the Google Earth API plugin.

Examples of the various visualisations are shown in Figures 4-9. Figure 4 shows the structure plan with just the regions as well as with the icons and extra data. In Figure 5 icons for all the beaches are displayed for the Cape Range National Park. Zooming in reveals more details about more beaches as the icons separate but still stay the same size. Figure 6 shows an icon overlaid on the polygon for one beach. The polygon is only revealed by zooming in but then only one beach is visible. By mousing over the icon, a graph is revealed that gives detail of the visitations for the beach over a number of years. Figure 7 shows the use of 2D and 3D polygons to display growth in housing, hotel occupancy and caravans for Exmouth. In the upper image, the polygon at top left is opaque because it is filled with houses whereas the large polygon at centre bottom is fully transparent revealing no houses present. The lower image shows the same information displayed as volumes of the 3D polygons with the level of fill corresponding to occupancy. Figure 8 shows a number of houses randomly placed on a rectangular grid for one of the residential areas in Exmouth that blend reasonably well into the background imagery. Finally Figure 9 shows the use of 3D models of people and beach umbrellas used to show beach occupancy.

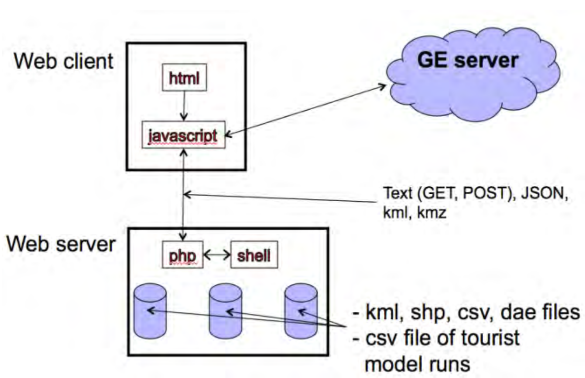

Figure 3: Architecture of the web pages

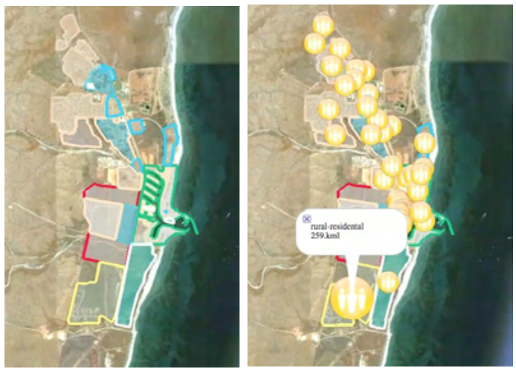

Figure 4: Regional plan and icons for Exmouth

Figure 5: Beach icons

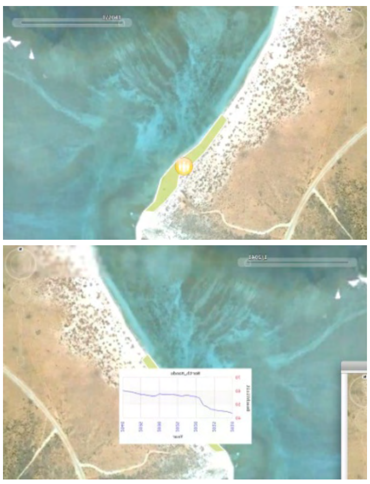

Figure 6: One beach

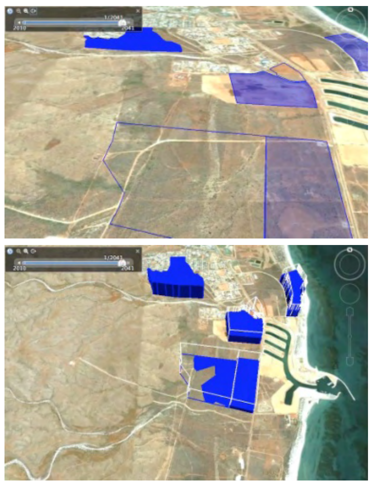

Figure 7: 2D and 3D regions

Figure 8: 2D house images

Figure 9: 3D models on a beach, overview and zoomed in

4. DISCUSSION

Judging the success of a digital earth in representing future scenarios requires a return to the issues facing the representation of complex datasets and the extent to which they have been resolved. The first issue was how to make the data immediately apparent to users to avoid lengthy textual explanations. Using a digital earth immediately eliminates the need for spatial explanations when data is intelligently linked to its spatial location. The capacity to zoom in also allows users to choose a level of complexity with which they are comfortable when more than one dataset is displayed. Shading and adding a height dimension are useful in an urban context where particular spaces have specific functions (for instance, residential, industrial, etc). The use of 2D and 3D object representations has the advantage of being immediately recognisable. More than one type of representation provides users with the capacity to choose their preferred method.

A digital earth offer benefits when presenting data at different scales, depending on the kind of representation used. The most effective method was the simplest: the use of icons that varied in size as determined by the tourism model, and would always remain visible. Icons can also be chosen to be immediately recognisable to users, and more icons become visible as users magnify a particular area. An issue is the possible confusion of icons if many are presented, but this can be controlled through scaling and providing users with the option of choosing particular datasets. Note that comparison between NDM model runs is more easily carried out in a table or graph than in a digital earth. The technique employed was to provide four datasets for the users, who could compare them separately. The interface also provided an option to load datasets in new tabs or windows allowing users to flick between them, with the different scenarios clearly labelled.

A key element of this process is to focus users on learning from the data rather than becoming fixated on a specific representation, such as a hotel located close to their place of residence. Some of the techniques are more likely to cause consternation than others, in particular the 2D and 3D models. While random placement of 2D and 3D models addresses this to a degree, using techniques such as shading or adding a height dimension to an area may better focus users on learning when decisions are contentious.

A digital earth is becoming important for representing complex datasets across a wide range of indicators in a way that makes them manageable for users. Users choose the scale at which they want to engage (many will be more interested in specific locations than a region as a whole) and turn on and off the representations as required. Nevertheless, there is no substitute for goal-oriented design to present the data in the best way. The data available needs to be linked to a specific purpose, in our case communicating the economic, social and environmental impacts of four different tourism scenarios. Rather than present all the information available, it is necessary to present data that represent each of the tourism impacts, facilitating comparisons between the four scenarios to changes in tourism.

Finally, digital earth environments are becoming increasingly popular. At this point in time they have enough appeal for users to invest their time in exploring a set of results in much greater detail than would be the case in other methods of representation. Furthermore, the new techniques of representing change link directly to user knowledge and connection to place in a way that is not possible through graphs or even static maps. This has benefits in that it increases the importance of research results for users, while also raising again the issue of how to present modelling results in a way that teaches without unduly alarming.

6. CONCLUSIONS

This paper has investigated digital earth techniques for visualising aspects of a tourism model for the Ningaloo region of Western Australia. A digital earth allows the use of traditional static cartographic methods as well as dynamic methods including changing polygon shading, changing icon size and the use of 3D representations. Importantly it was discovered that one method of visualisation was not suited to all situations. For example, narrow long regions such as beaches were hard to show by varying polygon opacity over time but the information could be displayed with varying sized icons. The use of 3D models was found to be impractical for hundreds of models and the models did not integrate well with the underlying satellite imagery. While this could be resolved through developing a full 3D environment, this will be impractical and too expensive for rural and remote regions. For these reasons, it is likely that 2D models and icons will be deemed to have more utility in current digital earth environments. Traditional cartographic techniques should also be considered, particularly where they can be made dynamic to represent changes into the future.

The current form of the visualisation is mainly for evaluation and the intention is to modify it to make it more user friendly and to fit in with other visualisation web pages for a seamless collection of methods to get the various messages across to the various stakeholders and users. While this paper has explored the techniques required to represent modelling data and enhance the prospects of a general audience engaging and learning from research results, success will be judged in users' responses to the interface and their preferred methods of viewing change. Future research will investigate how users use the interface and tools, and will undertake surveys of users to assess the different methods of representation. The framework for delivering the research results via a Google Earth plugin embedded in a webpage demonstrates that research can use a digital earth to communicate to a general audience. This paper explored some methods through which this is possible and we are to entering a period where projects that produce socio-economic simulations and models will break new ground in conjunction with further innovations in the digital earth environment.

REFERENCES

[1.] Department of Conservation and Land Management, *Management Plan for the Ningaloo Marine Park and Muiron Islands Marine Management Area, 2005-2015*; Department of Conservation and Land Management: Perth, 2005.

[2.] Craglia, M., M.F. Goodchild, A. Annoni, G. Camara, M. Gould, W. Kuhn, D. Mark, I. Masser, D. Maguire, S. Liang, and E. Parsons: Next-Generation Digital Earth. *International Journal of Spatial Data Infrastructures Research*, Vol. 28, pp. 146-67 (2008).

[3.] Ingram, C., *Parks, People and Planning: Local Perceptions of Park Management on the Ningaloo Coast, North West Cape, Western Australia*, in *Department of Social Science*; Curtin University: Perth, 2008.

[4.] Jones, R. and J. Selwood: From 'Shackies' to Silver Nomads: Coastal Recreation and Coastal Heritage in Western Australia in *Heritages from Below*, I. Robertson, Editor; Ashgate, Aldershot, In press.

[5.] Leiper, N.: Why 'the tourism industry' is misleading as a generic expression: The case for the plural variation, 'tourism industries'. *Tourism Management*, Vol. 29, pp. 237-57 (2008).

[6.] Western Australian Tourism Commission, *Gascoyne Region Tourism Product and Infrastructure Development Plan 2004 - 2013*; Western Australian Tourism Commission: Perth, 2003.

[7.] Jones, T., M. Hughes, D. Wood, A. Lewis, and P. Chandler, *Ningaloo Coast Region Visitor Statistics: Collected for the Ningaloo Destination Modelling Project*; Sustainable Tourism Cooperative Research Centre: Gold Coast, 2009.

[8.] Jones, R., C. Ingram, and A. Kingham: Waltzing the heritage icons: 'swagmen', 'squatters' and 'troopers' at North West Cape and Ningaloo Reef, in *Geographies of Australian Heritages.*

Loving a Sunburnt Country, R. Jones and B. Shaw, Editors; Ashgate, Hampshire, 2007, pp. 79-94.
[9.] Jones, T., J. Glasson, D. Wood, and B. Fulton: Regional Planning and Resilient Futures: Destination Modelling and Tourism Development - the case of the Ningaloo Coastal Region in Western Australia*. Planning Practice and Research*, (In press).
[10.] Jones, T. and D. Wood: Researching tourism to the Ningaloo Reef, Western Australia, or how the social sciences can collaborate in researching complex problems*. Interdisciplinary Journal of the Social Sciences*, Vol. 3, pp. 137-44 (2008).
[11.] Jones, T., D. Wood, M. Hughes, T. Pham, D. Pambudi, R. Spurr, L. Dwyer, M. Deery, and L. Fredline, *Tourism Destination Modelling: Building a Sustainable Planning Tool for Australian Tourism Destinations*; Sustainable Tourism Cooperative Researchh Centre: Gold Coast, 2010.
[12.] Schianetz, K., T. Jones, L. Kavanagh, P.A. Walker, D. Lockington, and D. Wood: The practicalities of a learning tourism destination: a case study of the Ningaloo Coast*. International Journal of Tourism Research*, Vol. 11, pp. 567-81 (2009).
[13.] Senge, P.M., *The Fifth Discipline: The Art and Practice of the Learning Organization*; Currency Doubleday, New York, 1990.
[14.] van den Belt, M., *Mediated Modeling: A Systems Dynamics Approach to Environmental Consensus Building*; Washington, Island Press, 2004.
[15.] Western Australian Planning Commission, *Ningaloo Coast Regional Strategy Carnarvon to Exmouth*; Western Australian Planning Commission: Perth, Australia, 2004.
[16.] Smallwood, C.B., L.E. Beckley, S.A. Moore, and H.T. Kobyrn: Assessing patterns of recreational use in large marine parks: A case study from Ningaloo Marine Park, Australia*. Ocean & Coastal Management*, Vol. 54, pp. 330-40 (2011).

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

AN ARCHITECTURE FOR MANAGING SCHEMA EVOLUTION IN A FEDERATED SPATIAL DATABASE SYSTEM

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ABSTRACT

A Federated Spatial Database System (FSDBS) is the integration of multiple spatial data sources and the realisation of effective spatial data sharing. FSDBS environments are becoming increasingly popular as more and more spatial and non-spatial datasets are integrated, especially those across a number of independent organisations. However, in a FSDBS environment, database schemas are subject to change and the management of these changes is complex and inefficient. This is because schema changes in one local database will affect or invalidate not only applications built against this local schema, but also applications built against the global schema.

In this research, a Schema Element Dependency Meta-model and a set of Schema Change Templates which incorporates view generation, view rewriting and query rewriting have been developed as the solution in managing schema evolution in a FSDBS. This paper focuses on the architecture of Automatic Schema Evolution that includes a schema element dependency tool, a schema mapping tool and a view rewriting tool. These tools are embedded with the developed methods will assist in effective management of schema evolution in a FSDBS and engendering collaboration and interoperability between data custodians and application developers and users.

1. INTRODUCTION

This research proposed methodologies to deal with schema changes that can occur in a Federated Spatial Database environment in which queries are built on one or more databases that may not be under the control of the federated database administrator. A spatial database system is distinguished from a non-spatial database system through the inclusion of [1]:

- spatial data objects such as points, lines and polygons;
- methods to process spatial data such as spatial indexes, extended spatial query languages and effective algorithms for spatial operations;

as well as the normal data types and methods for non-spatial data. A Spatial Database Management System (SDBMS) manages and manipulates a spatial database [2].

In a traditional database, a view is defined as a stored query, usually as SQL statements. In many cases, a spatial view extends the traditional view by adding a spatial field. Such spatial views are created in the same way as traditional non-spatial views and stored as spatial queries that contain the spatial attribute and spatial operations such as spatial selection and spatial joins.

A Federated Spatial Database System (FSDBS) integrates various geographically distributed spatial databases and sources and provides a unified data access mechanism in order to facilitate spatial data sharing [1]. This has been achieved through advancements in networks and communications, distributed computing technologies, and conformance with standards and policies. FSDBSs have been the subject of active research for dealing with database heterogeneity [3] [4] and are seen as an important part of any proposed Spatial Data Infrastructure (SDI).

A traditional database can be described by schemas that define relations, attributes etc. A spatial database schema is an extension of the traditional schema to include spatial descriptions and behaviours required for a spatial database [1]. Spatial database schemas, like non-spatial schemas, are subject to change or evolution due to changes in perception of reality and application requirements.

Schema changes often result in applications built against the schemas being affected or even invalidated. In a FSDBS, the federated schema is dependent on local schemas so when a local schema changes, applications built on local schemas and federated schemas and applications built on the federated schemas will be affected. Managing schema evolution overcomes the mismatch between applications and the evolved schemas, and maintains consistency of the correspondences between schemas after schema changes.

Currently schema management is performed manually and there is a need to develop methods that can be used to automatically or semi-automatically deal with schema evolution. The Automatic Schema Evolution (ASE) architecture proposed in this paper defines the components and functionalities of each component. With the ASE, schema evolution in a FSDBS can be managed in a semi-automatic and, in the future, in an automatic manner.

2. QUERY AND VIEW REWRITING

Query rewriting is the main method used to deal with schema evolution. It relies on schema mapping that specifies the correspondences between schemas [5]. In a FSDBS, a query imposed on the global schema is typically decomposed into a number of sub-queries imposed on local schemas. The decomposition here depends on mapping information typically stored as metadata.

In a FSDBS, schema mapping consists of (i) mapping between local database schemas and the federated global schema, and (ii) mapping between different schema versions of each system.

Query rewriting is the process of converting query statements into different expressions while still keeping the logical structure of the query [6]. Equivalent query rewriting occurs when the result of a rewritten query is equivalent to the results of the original query. Query rewriting has been widely studied for different applications such as query optimisation, data integration, data exchange and schema evolution [7]. For example, rewriting queries with materialised views has attracted attention for performance improvement of a database system. Different query rewriting algorithms have been

developed to rewrite queries with views [8] [9] [10]. Rewriting queries against one schema into equivalent ones against another schema has been adopted as a solution to schema integration, schema transformation and schema evolution[6] [11] [12].
There are a number of different approaches that have been proposed for representing schema mapping: Global-As-View (GAV), Local-As-View (LAV) and Global-Local-As-View (GLAV) [13] [14]. GAV has been adopted in this research due to its simplicity for query rewriting and the fact that the combination of two GAV mappings is still a GAV mapping. Therefore, schema mapping in this research is restricted to this form of GAV mapping that consists of unfolding and substitution [15]. Unfolding is when a query defined as a combination of sub-queries is rewritten as a combination of the components of the sub-queries i.e. a form of factorisation that allows manipulation of the components to produce new queries. Substitution is where a new query is generated to replace an old query. Queries expressed against the global schema can be rewritten as equivalent ones against the source schemas. Similarly, queries expressed against old schemas can be rewritten against the new schemas.

3. ARCHITECTURE OF AUTOMATIC SCHEMA EVOLUTION

Figure 1 illustrates the architecture of the ASE. There are five main components included: spatial data repositories, a metadata repository, a view rewriting tool, a schema mapping tool and a schema element dependency tool.

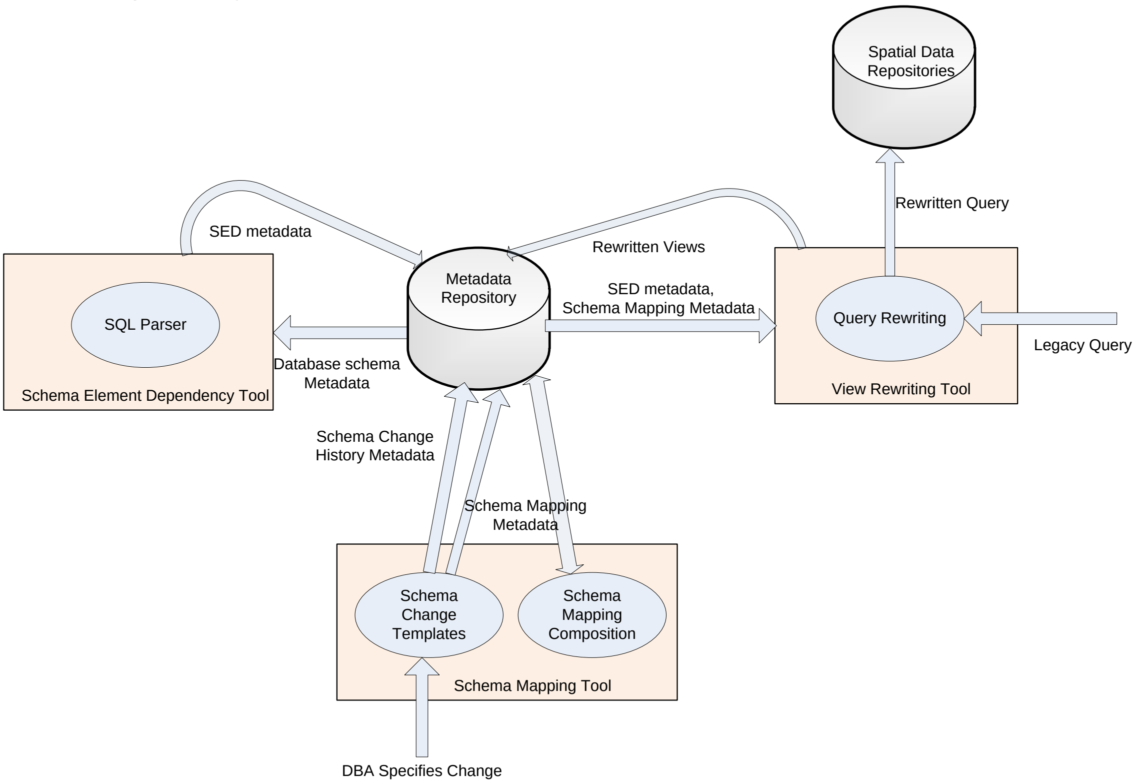

Figure 1. The ASE architecture

3.1. Spatial Data Repositories

The Spatial Data Repositories include local spatial databases and the federated spatial database. Local spatial databases contain base tables that store spatial and non-spatial data and views. The federated spatial database consists of tables and views as a virtual database built on the distributed local databases. That is the federated spatial database doesn't contain any data as this is stored in local spatial databases. Queries on the federated database, including new queries, are indicated as "legacy queries" in Figure 1.

3.2. Metadata Repository

Metadata is data about data [16]. In this research, metadata is treated as the first class for schema evolution management. The metadata repository stores various types of metadata and provides a consistent and united access mechanism to data to improve the effectiveness of information management. As shown in Figure 1, the three main processes are linked to the metadata repository. There are four types of metadata in the repository: (i) schema element dependency metadata; (ii) schema mapping metadata; (iii) schema change history metadata; and (iv) metadata from which the schema element dependencies are derived.

3.3. Schema Mapping Tool

The Schema Mapping Tool in Figure 1 imbeds two modules: Schema Change Templates (SCTs) and Schema Mapping Composition. The functionality of this tool is to generate and update schema mapping metadata which then can be used for view/query rewriting.

SCTs represent all schema change scenarios that can occur in a spatial database environment and satisfy different schema changes. Based on mapping between the conceptual spatial schema and SQL schema (the implementation schema), a set of SCTs can be generalised in SQL schema as shown in Table 1.

Table 1. Mapping between Conceptual Spatial Schema and SQL Schema

Conceptual Spatial Schema	SQL Schema
Feature Object Class	Table (one or more tables depending on the data types supported by the DBMS[17])
Non-spatial Object Class	Table
Spatial Attributes	Geometry Column or Geometry table with reference to the feature table [17]
Non-Spatial Attribute	Column
Relationship	Foreign Key and Primary Key (1:1 or 1:M)
	Table with two Foreign Keys (M:N)

In this research, schema change is treated as schema mapping. So each schema change in the SCTs has corresponding schema mapping rules. Table 2 lists the mapping rules related to each SCT where A, B, C & D are sets of attributes, a, b, c & d are single attributes, and R, T & S are tables. The symbols are the normal relational algebra symbols: π, σ, $\bowtie$, U and $\leftarrow$ and mean project, select, join, decompose and rewrite respectively. When a schema change is specified by the DBA, schema mapping metadata between schema versions of before and after change are generated. The SCTs also can advise whether or not a view should be generated. For example, after renaming a table, a view with the same name of the original table can be generated that references the renamed table.

Table 2. Schema Change & Corresponding Schema Mapping

Schema Change	Input Schema	Output Schema	Schema Mapping
Add a column	R(A)	R(A,b)	π R(A) $\leftarrow$ π R(A,b)
Add a table		T(A)	
Rename a table	R(A)	T(A)	R(A) $\leftarrow$ T(A)
Merge tables	R(A), S(A)	T(A,b) [1]	R(A) $\leftarrow$ σ (T(A,b)), S(A) $\leftarrow$ σ (T(A,b))
Join tables	R(a,B), S(a,C) [2]	T(a,B,C)	R(a,B)$\leftarrow$ π T(a,B,C) S(a,C)$\leftarrow$ π T(a,B,C)
Split a table	R(a,B,C)	S(a,B), T(a,C)	R(a,B,C)$\leftarrow$S(a,B) T(a,C)
Decompose a table	R(A)	S(A), T(A)	R(A) $\leftarrow$ S(A) $\cup$ T(A)
Move a column	R(a,B,c) ,S(a,D)	R(a,B) ,S(a,c,D)	R(a,B,c) $\leftarrow$ π σ (R(a,B) $\bowtie$ S(a,c,D)); S(a,D) $\leftarrow$ π S(a,c,D)
Split a column	R(a,B)	R(c,d,B)	R(a) $\leftarrow$F(R(c,d))
Merge columns	R(a,b,C)	R(d,C)	R(a) $\leftarrow F_1$(R(d)), R(b) $\leftarrow F_2$(R(d))

[1] In order to be able represent mapping in GAV, a column is added as the condition when two tables are merged;
[2] To avoid data loss, when join tables, outer join is needed

Schema Mapping Composition is used to combine schema mappings and schema evolution can result in the existing schema mapping being invalid. In order to ensure the consistency of schema mapping, schema mapping combines two schema mappings into one [18]. This approach can be applied to vertical and horizontal mapping. When a data source schema changes, a new schema mapping between the global schemas and local schemas can be derived from the original mapping and the change schema mapping. Likewise, for the local schemas, schema mapping between older versions and the current one can be derived from the schema changes and the old schema mapping.

3.4. Schema Element Dependency Tool

The Schema Element Dependency (SED) tool in Figure 1 is used to generate column level SED metadata for a newly created view, and to update the SED metadata when a view is rewritten. The SQL Parser module embedded with this tool is based on the SED metamodel developed in this research. According to the SED metadata, the impact of schema changes can be analysed, and, affected views can be detected for view rewriting.

3.5. View Rewriting Tool

The Query Rewriting module, embedded in the View Rewriting Tool in Figure 1 is used to rewrite queries against one schema into queries against another schema according to the schema mapping. Since a view is a stored query, view rewriting can be regarded as being similar to query rewriting. The View Rewriting Tool identifies views (spatial views and non-spatial views) according to SED metadata and then rewrites and recompiles them according to the schema mapping metadata.
However, there is a difference between view rewriting and query rewriting. View rewriting is a one-off operation as it only occurs when schema changes occur. Query rewriting happens every time the query is processed. This is because any affected view can be detected from the SEDs while the queries from the application can only be detected when they are processed.

3.6. Example of Schema Updating

Figure 2 shows an example road spatial database schema S and two proposed schema changes for S. The first one is to merge *ExisingMainRoads* and *ProposedMainRoads* into *MainRoads*, and the second one is to split *MainRoads* into *MainRoads* and *RoadNames*. In addition a spatial view *Highways* is built against schema S_1 to display all the highways.

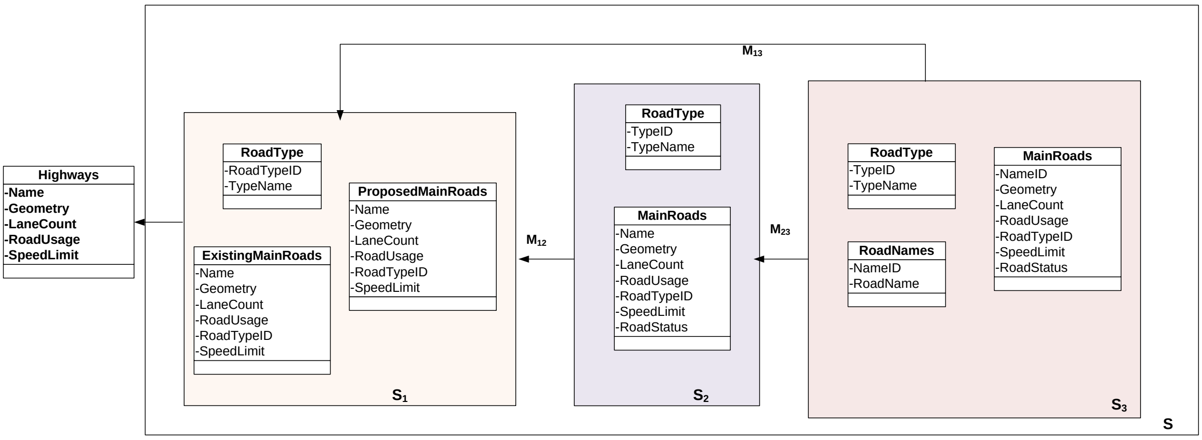

Figure 2. Schema Changes in S

When a schema changes, the DBA specifies the schema change using the schema mapping tool. Then the required schema mappings M_{12} and M_{23} are generated according to the schema mapping rules defined in the SCTs. In addition, schema mapping M_{13} is also generated by combining M_{12} and M_{23}. Table 3 lists the schema mappings generated by the schema changes and schema composition (in the form of GAV).

Table 3. Schema Mapping in S

Mapping Name	Schema Mapping
M_{12} (mapping between S_1 and S_2)	*S_1.ExistingMainRoads (n, g, lc, ru, sl, rtID) ← σ rs = 'Existing' (S_2.MainRoads (n, g, lc,ru, sl, rs, rtID))*
	S_1.ProposedMainRoads (n, g, lc,ru, sl,rtID) ← σ rs = 'Proposed' (S_2.MainRoads (n, g, lc,ru, sl, rs, rtID))
M_{23}(mapping between S_2 and S_3)	*S_2.MainRoads (n, g, lc,ru, sl, rs, rtID) ← S_3.MainRoads (nID, g, lc,ru, sl, rs, rtID) ⋈ S_3.RoadNames (nID, rn)*
M_{13} (mapping between S_1 and S_3)	*S_1.ExistingMainRoads (n, g, lc,ru, sl,rtID) ← σ rs ='Existing'(S_3.MainRoads (nID, g, lc,ru, sl, rs, rtID) ⋈ S_3.RoadNames (nID, rn))*
	S_1.ProposedMainRoads (n, g, lc,ru, sl,rtID) ← σ rs ='Proposed'(S_3.MainRoads (nID, g, lc,ru, sl, rs, rtID) ⋈ S_3.RoadNames (nID, rn))

Where n, g, lc, ru, sl, rs, rtID, nID and rn denote Name, Geometry, LaneCount, RoadUsage, SpeedLimit, RoadStatus, RoadTypeID, NameID and RoadName respectively.

When schema S changes from S_1 to S_2, *Highways* built against S_1 will be invalid. The view rewriting tool rewrites and recompiles *Highways* to accommodate the schema change. Table 4 shows the rewriting of *Highways* (expressed in relational algebra) after schema S changes from S_1 to S_2. More comprehensive examples can be found in [19].

Table 4. Rewriting of Spatial View - *Highways*

Before Rewriting (against S_1)	**After Rewriting (against S_2)**
σ *tn* = '*highway*'((S_1.*ExistingMainRoads*(*n, g, lc, sl,rtID*) $\cup$ S_1.*ProposedMainRoads* (*n, g, lc, sl, rtID*)) $\bowtie$ S_1.*RoadType* (*tID, tn*))	σ *tn* = '*highway*' ((σ *rs* = '*Existing*' $\cup$ σ *rs* = '*Proposed*' (S_2.*MainRoads* (*n, g, lc,ru, sl, rs, rtID*) $\bowtie$ S_2.*RoadType* (*tID, tn*))

4. SUMMARY

Schema evolution is essential in a FSDBS because in many implementations, it is dependent on databases owned, maintained, and importantly are modified by other organisations. Managing schema evolution in such an environment is a significant challenge. This paper proposes methodologies to enable semi-automatic management of schema evolution in a FSDBS environment so that schema changes will be transparent to applications and users. To achieve this, SEDs across databases are determined, and, a set of SCTs proposed to define a rich bounded set of schema change scenarios in a spatial database environment, and provide the mapping rules for each change. View generation/rewriting and query rewriting are proposed as the solution to allow changes to the various databases to be accommodated.

Effective management of schema evolution in a FSDBS is an integral part of an SDI. It ensures discovery and access to spatial data and services is continuous even though schema changes have occurred. It also provides schema evolution transparency to end-users and minimises modification of applications thus saving time and money. Effective management of schema evolution also increases the reusability of spatial data; ensures the longevity of spatial data and services well into the future; improves spatial data and service management; and engenders collaboration and interoperability between data custodians and application developers and users.

ACKNOWLEDGEMENT

The authors would like to thank Landgate and Curtin University for providing funds to support this PhD research.

REFERENCES

1. Yeung, A.K.W. and G.B. Hall, *Spatial Database Systems - Design, Implementation and Project Management*. Vol. 87. 2007: Springer.
2. Rigaux, P., M. Scholl, and A. Voisard, *Spatial Database - with Application to GIS*. 2002: Morgan Kaufmann 410.
3. Litwin, W., L. Mark, and N. Roussoupoulos, *Interoperability of Multiple Autonomous Databases.* ACM Computing Surveys, 1990. **22**(3): p. 267-293.
4. Sheth, A.P. and J.A. Larson, *Federated Database Systems for Managing Distributed, Heterogeneous, and Autonomous Databases.* ACM Computing Surveys (CSUR), 1990. **22**(3): p. 183-236.

5. Bernstein, P.A., et al., *Implementing mapping composition*, in *Proceedings of the 32nd international conference on Very large data bases*. 2006, VLDB Endowment: Seoul, Korea. p. 55-66.

6. Deutsch, A., L. Popa, and V. Tannen, *Query reformulation with constraints*, in *SIGMOD Rec.* 2006. p. 65-73.

7. Halevy, A.Y., *Answering queries using views: A survey.* The VLDB Journal, 2001. **10**(4): p. 270-294.

8. Duschka, O.M. and M.R. Genesereth, *Answering recursive queries using views*, in *Proceedings of the sixteenth ACM SIGACT-SIGMOD-SIGART symposium on Principles of database systems*. 1997, ACM: Tucson, Arizona, United States.

9. Popa, L., *Object/Relational Query Optimization with Chase and Backchase*, in *Institute for Research in Cognitive Science*. 2001, University of Pennsylvania. p. 212.

10. Levy, A.Y., A. Rajaraman, and J.J. Ordille, *Querying Heterogeneous Information Sources Using Source Descriptions*, in *Proceedings of the 22th International Conference on Very Large Data Bases*. 1996, Morgan Kaufmann Publishers Inc.

11. Curino, C., et al., *Schema Evolution in Wikipedia - toward a Web Information System Benchmark.* ICEIS, 2008.

12. Wiederhold, G., *Mediators in the Architecture of Future Information Systems.* Computer, 1992. **25**(3): p. 38-49.

13. Cali, A., et al., *On the Expressive Power of Data Integration Systems*, in *Proceedings of the 21st International Conference on Conceptual Modeling*. 2002, Springer-Verlag.

14. Lenzerini, M., *Data integration: a theoretical perspective*, in *Proceedings of the twenty-first ACM SIGMOD-SIGACT-SIGART symposium on Principles of database systems*. 2002, ACM: Madison, Wisconsin.

15. Cali, A., *Reasoning in Data Integration Systems: Why LAV and GAV are Siblings.* Springer Berlin / Heidelberg, 2003: p. 9.

16. Sen, A., *Metadata management: past, present and future.* Decision Support Systems, 2004. **37**(1): p. 151-173.

17. OGC (2006) *OpenGIS® Implementation Specification for Geographic information - Simple feature access - Part 2: SQL option*.

18. Nash, A., P.A. Bernstein, and S. Melnik, *Composition of mappings given by embedded dependencies.* ACM Trans. Database Syst., 2007. **32**(1): p. 4.

19. Wu, X., et al., *Managing Schema Evolution in a Federated Spatial Database System*, in *Discovery of Geospatial Resources: Methodologies, Technologies and, Emergent Applications*. 2011, IGI Global.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

THERE-DIMENSIONAL LASER SCANNER TO DETECT LARGE RESERVOIR LANDSLIDE DISPLACEMENT

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ABSTRACT

The three-dimensional laser scanner, due to its high efficiency, high density and high resolution in terrain data acquisition , is frequently applied to the deformation monitoring for landslide risk reduction in recent years. Landslide movement can be detected by means of comparison of sequential scans. The technique is adopted in the study of a complex landslide Jinpingzi located in Wudongde Reservoir, Yunnan Province (Southeast China). After the data acquisition from the field and the data pre-process, four approaches, comparison of DEM (Digital Elevation Model), section, point cloud and fixed point, have demonstrated to be feasible and effective. The deformation volume of the landslide is computed. The results indicate the high level of landslide activity in the past one year. Besides, the comparison of different method is done in this paper.

1. INTRODUCTION

Considered as a major hazard and widely concerned issue in reservoir regions, large reservoir landslide always endangers the reservoir normal water storage and the safety of people’s life and property around the regions. Large reservoir landslide can obstruct river channels, lift the water level of reservoir and overlap or break the dam, which would probably cause catastrophic flood, such as the astonishing tragedy in Vaiont, Italy. In recent years, for predicting hazards and preventing the damage, researchers have done a large amount of work in monitoring landslides besides trying to explain the formation mechanism and sliding movement rule of landslide. Especially for the large reservoir landslide in rapid deformation period, monitoring displacement has become the central work and critical issue.

Displacement monitoring techniques can be divided into two categories: (1) Point based techniques (GPS, extensometer, total station, laser and radar distance meter) [1,2]; (2) surface based techniques (photogrammetry, satellite-based and ground-based radar interferometry, aerial laser scanning and Terrestrial Laser Scanning [3]). Generally, point based measurements can offer a better precision than surface based techniques. However, they are limited in projects related to lager area since they only provide information on some selected and fixed monitoring points but not the surface over the whole landslide. As a surface based technique of monitoring, the three-dimensional laser scanning makes the 3D point cloud acquisition completed in short time. Hundreds of thousands of laser beams are emitted per second and high precision data of the surveying surface are obtained based on the time-of-flight laser measurement technique[4].Compared to traditional measurement techniques, three-dimensional laser scanning is more effective and convenient in terrestrial data acquisition. For the landslide during accelerated deformation period or failure period, such a real-time, surface based and high precision monitoring technique can play an essential part in predicting landslide hazard.

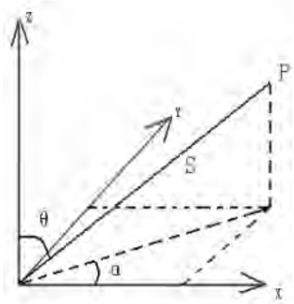
As a promising monitoring technique, three-dimensional laser scanning is applied in rock slope characterization and monitoring in many cases. The deformation of the terrain of rocks can be detected via the comparison of sequential laser scans (Crosta et al.,2003;Bauer et al., 2005; Oppikofer et al., 2008a; A. Abell´an et al.,2009)[5-8].These works proves that 3D laser scanning is feasible and convenient for detecting displacement and quantifying the deformation with centimeter level accuracy.For largereservoir landslide,one question that remains to be resolved is as follows: thewater storage of reservoir or heavy weather condition may cause the potentialreservoir landslide failure. How to detect the landslide displacement before its failure quickly and effectively? Some measures must be taken to accelerate the processing. Will the post processing of datamaskprecursory deformation? The aims of this study are: (1) to develop a methodologythat is no need to detect millimetric/centimetric scale deformation but that can detect the deformation quickly and effectively. (2) to apply this methodologyto detect a precursory deformation on a real falling reservoir landslide.

2. PRINCIPLE AND METHODS

2.1. PRINCIPLE OF THREE-DIMENSIONAL LASER SCANNING ACQUISITIONS

Based on the time-of-flight principle [4], three-dimensional laser scanner can obtain a 3D point cloud of the complex topographic unstable sites. A laser beam sweeps the surveying surface by the rotated mirror fixed in the laser scanner. When the laser pulse is received, some information, like the angles of emission and the travel time of the laser pulse, are restored. Then the coordinates of the reflective point can be figured out through the distance S, horizontal emission angle α and vertical emission angle θ of each single laser beam. After the transformation from scanner own coordinates (polar coordinate system) to project coordinates (Cartesian coordinate system), raw data have to be processed in order to extract the topography.

The main two factors that influence the spatial resolution of the 3D point cloud largely are the angular resolution for laser beam emission and the distance between 3D laser scanner and surveyed objects. Usually, we can obtain high resolution terrestrial data by means of promoting the angular resolution when the distance is certain. However, one of the most serious disadvantages of this technique lies in the no data zone caused by occluding objects where the laser beam cannot pass through. To overcome this disadvantage, several acquisitions should be taken from different set-up stations [9]. Also, there have to be several critical reflected points in each station to combine the point clouds acquired from each scan position. Then the high density of the point cloud can be provided, but the point cloud cannot be used directly because of their confusion. The large volume of point cloud data, about several GB, is a challenge for data processing and analysing. And usually in raw data, there are a great many error points, acnode, virtual points and false points that must be filtered and cancelled. Consequently, a suitable and effective method of filtering raw data is also important.



$$X = S\cos\theta\cos\alpha$$
$$Y = S\cos\theta\sin\alpha$$
$$Z = S\sin\theta$$

Figure 1:transformation from scanner own coordinates (polar coordinate system) to project coordinates (Cartesian coordinate system)

2.2. CHARACTERISTICS OF THE RIEGL VZ-400

The RIEGL VZ-400 has been employed to acquire point clouds in our case discussed later. The objects are essentially characterized by its narrow beam divergence (0.0005 rad), wide operating range (0° to 100° vertically, 0° to 360° horizontally), and a frequency of about 300,000 points per second. The measuring range is announced up to 500 m. The single point accuracy announced for VZ-400 is 2 mm at 100 m.The software RiSCAN PRO has installed and applied to sensor configuration, data acquisition, raw data pro-processing and storage.

2.3. DISPLACEMENT CHARACTERIZATION AND QUANTIFICATION

Point cloud data can be analysed in many kinds ofmethods for the landslide displacement characterization, such as DEM s comparison [10], point to point comparison, certain fixed point comparison and transectscomparison. The quantification of displacements of the landslide can be achieved by means of DEMs comparison. But for the large reservoir landslide, 1 m cell-size DEMs are generated for each acquisition. Because of the occlusions, DEMs cannot be directly compared and shadow areas were not taken in account.

Before creating DEMs, post-processing is carried out by RiSCAN PRO algorithms to extract only the back-scattered pulses due to the topography. Density calculations and raster DEMs have been computed thanks to the plat of Geographic Information System(GIS): Density is obtained by statistics method and DEMs computation uses Kriging interpolation.And anearest neighbour method is adopted in the comparison of point to point. Besides, in order to detect the deformation of the fixed monitoring point, manual elimination of the vegetation points is made, which provides base for the statistics under different radius with the fixed point as centre.

Before filteringAfter filtering

Figure2: Manual filtering in certain fixed monitoring point

3. RESULTS AND INTERPRETATIONS

3.1. THE JINPINGZI LANDSLIDE DISCRIPTION AND MONITORING

Jinpingzilandslide is located on the right bank of the downstream of Wudongde cascade reach of Jinshajiang River. The up distance of the slide to the Wudongde hydropower station is about 900 meters. Remote sensing interpretation volume of the landslide is about 620 million cubic meters. The stability, the transfiguration trend and the possible instabilizationmode and scale is associated with the establishment of cascade development of Wudongde hydropower station and the choice of the bank in the reach, so these factors attract the attentions of many areas.

Through comprehensive perambulation, geographic investigation and surveying and mapping, a study is conducted according to the geographic mapping and drilling and adit exploration by using comprehensive technical method, such as rock and soil test, deformation monitoring and so on. According to the study, Jinpingzi slide could be divided into five areas. Among these districts, the deformation of area II is the most distinctive. The up distance of the area, which mainly consists of colluvial and residual clay, to the location of Wudongde hydropower station is about 2.5 km. It is still in the process of deformation.

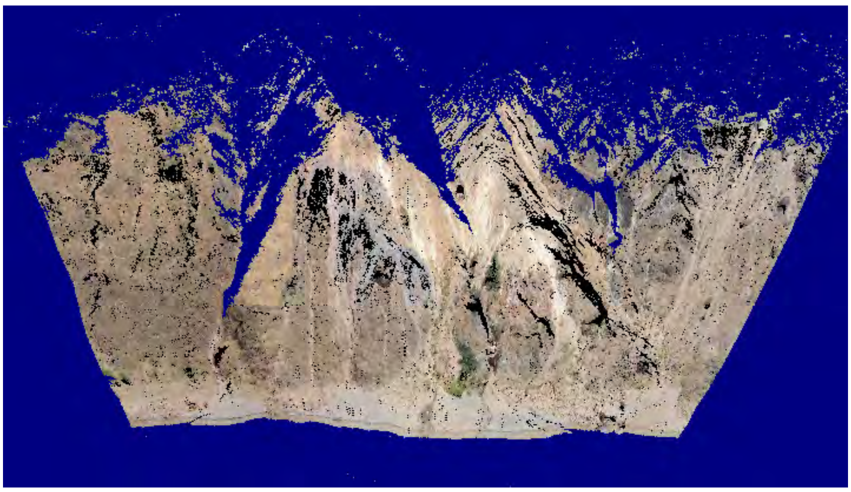


Figure 3: Points from the first scan,coloured by the RGB values asphotographed by the scanner's internal camera.

The conventional monitoring is started from October, 2004. There are 17 monitoring points in the severely deforming area II including horizontal and vertical displacement monitoring points. The 3D laser scanning technique was applied in the project in 2009. And there are two acquisitions taken in 30 May,2009 and 14 May,2010 to detect the displacement of this large reservoirs landslide. The angular resolution for laser beam emission of the first acquisition is 0.15 degreeand the second acquisition is 0.02 degree with a round 450m distance between 3D laser scanner and surveyed objects. Six set-up stations were needed in this project in order to cover 85% surface of the landslide.

3.2. DEMS SUBTRACTION

Due to the large scale of point cloud, a filtering method that only one single middle point is selected in a cell is adopted to degrade the density of the points. In this case, the large surveyed landslide has been divided into hundreds of thousands of cells with 0.25m height and 0.25m width. A point with X, Y, Z coordinates in the core of the cell allows representing the cell. Moreover, the Z value of the point is an average value of the points in the cell which is represented. By means of this processing, the speed of data analysis is promoted sharply, but the density of terrain points degrades sharply too. According to the current work of researchers, DEMs subtractions can quantify the variations of topography. A changing value on Z-coordinates corresponds to subsidence or lift of the surface of landslide.

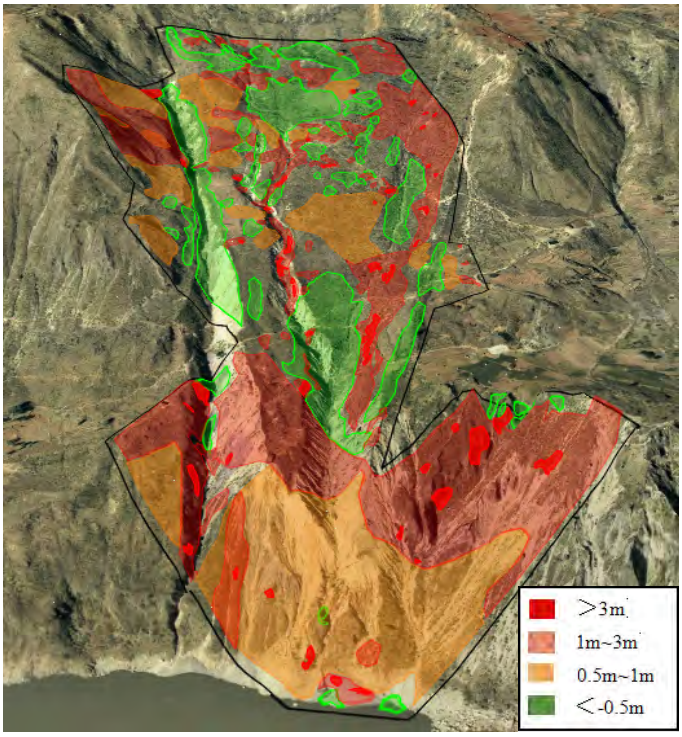


Figure 4: Results of DEMs subtractions in 3D image system

The landslide detection and quantification can be achieved by DEMs subtractions of sequential data. Results of the DEM subtractions are mapped in a three-dimensional image system. The deformation value is classified to four classes while thedeformation between subsidencedeformation (positive value) 0.5 m anduplift deformation (negative value)0.5 m is considered as no-deformationarea. The displacement of the landslide is divided into four partsasbellows:(1) subsidencedeformationbetween 0.5 m and 1 m (yellow area); (2)subsidencedeformation between 1 m and 3 m (orange area); (3)subsidencedeformation over 3 m (red area); (4) uplift deformation over 0.5 m (green area).Through the areas we can see the gullies where soil and rocks accumulate are in the green areas where uplift deformation happened, while the salient areas where soil and rocks are eroded are in the red, orange and yellow areas where subsidencedeformation happened. Finally, according to the result of raster calculation, the deformation volume of subsidencearea is 393,728m³ and the deformation volume of uplift area is 270,108 m³. The difference is 123,620m³.One major disadvantage of this approach is that the DEM subtraction is insufficient to completely characterize displacements, especially when DEM is notcompletebecause of occlusions.

3.3. SECTIONS COMPARASION

The deformation of the front of the landslide is most distinctive among the all areas. Four transects of the front of the landslide were also drawn through the DEMs with 1 m cell size. The distribution of the four transects is shown as figure. Also, the comparison of sections of sequential data was shown as figure. In the figure, the front of the section (Distance between 0 to 240m) except the point of gradient change deformed slightly. The deformation value is under 0.7 m. But the deformation value reaches 5 m at the gradient change point, and the average deformation value of the front of landslide is 0.9 m. The back of the section (Distance from 240 m to 320 m) is a platform's section with a maximum deformation of 8 m and an average deformation of 6 m. The general activity trend is subsidence. That showcases the high level of landslide activity in the past one year.

Figure 5: The section of the front of Jinpingzi landslide

3.4.COMPARISION OF CERTAIN FIXED POINT

In this case, the conventional monitoring point TP08 was chosen to demonstrate the comparison of certain fixed point. After manualelimination of the vegetation points, results can be achieved by statistics under the different radius.

Table 1:TP08 Z value by 3D laser scanning

Name	2009 Z/m (conventional)	2010 Z/m (3D laser scanning)			2009 Z/m (3D laser scanning)
		R=1m	R=2m	R=3m	R=3m
TP08	1180.592	1180.526	1180.230	1180.151	1181.075

According to the result under condition R=1 m, the Z value decreased 0.549 m from 2009 to 2010. By the total station data of recent years, the ratio ofhorizontal deformation and vertical deformation of the Jinpingzi landslide is about 1.910, so we presume the horizontal deformation from 2009 to 2010was 1.048 m.

3.5.POINT TO POINT COMPARISON

Figure shows the result of point to point comparison. The negative value means uplift deformation and positive value means subsidence deformation. The unit is meter.And the DEM subtraction was also made for comparison. The comparison is shown in figure.

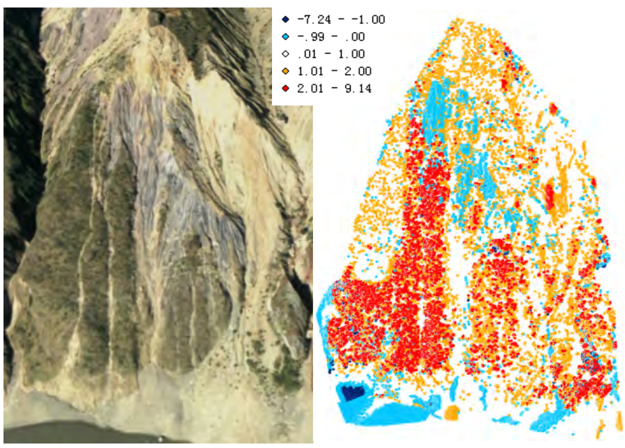


Figure 6: Comparison of point to point method in the front of Jinpingzi landslide

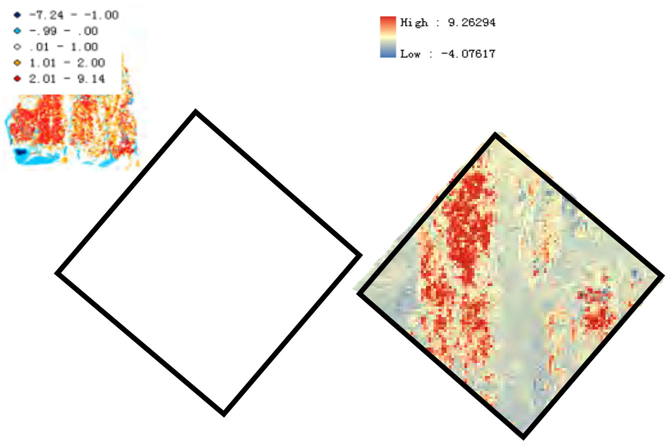


Figure 7: Comparison of results between DEMs subtractions
and point to point method

4. CONCLUSIONS AND FURTHER RESEARCH

From the sequential 3D laser scanning datasets, DEMs subtractionshave allowed us to spatially determine the displacement zones of the landslide. The most important drawback of this method lies in the fact that it offers information about altitude changes while vertical changes cannot be determined. Nevertheless, the comparisons ofsections which showcase the deformation visually were made.Also, in our case, 3D laser scanning proved to be a very suitable tool since it provides high resolute point clouds of the topography.For large reservoir landslide, deformation detection is very important for early-warning of the hazard. Sometimes, deformation should be detected as soon as possible, so the density of the points is not the higher the better because the. In our case, it proves DEMs with cell size 1 m are suitable for monitoring such a large landslide real time.As mentioned before, some point clouds have suffered from shaded areas of vegetation or chaotic zones. This problem makes a difference to the displacement characterization and quantification of the landslide. A better method for filtering point cloud should be proposed. And a monitoring system isdeveloped to monitoring the real-time displacement of landslide quickly and effectively.

REFERENCES

[1] AngeliM.C.,Pasuto, A.,Silvano, S. A critical review of landslide monitoring experiences. Eng. Geol. 2000, 55, 133–147.

[2] Squarzoni.C.,Delacourt. C.,Allemand. P. Differential single-frequency GPS monitoring of the La Valette landslide (French Alps). Eng. Geol. 2005, 79, 215–229.

[3]Johan K., Christophe D., Pascal A., Pierre P., Marion J.Application of a Terrestrial Laser Scanner (TLS) to the Study of the Séchilienne Landslide (Isère, France).Remote Sensing,2010, 2, 2785-2802.

[4]Lichti.D.D., Gordon, S.J., Stewart, M.P. Ground-based laser scanners: Operation, systems and applications. Geomatica 2002, 56, 21–33.

[5]Crosta, G. B. and Agliardi, F. Failure forecast for large rock slidesby surface displacement measurements, Can. Geotech. J., 40(1),176–191, 2003.

[6]Bauer.A., Paar.G., and Kaltenbock.A. Mass Movement MonitoringUsing Terrestrial Laser Scanner for Rock Fall Management,in*Geo-information for Disaster Management*, edited by: vanOosterom, P., Zlatanova, S., and Fendel, E. M., Springer, Berlin,393–406, 2005.

[7]Oppikofer.T., Jaboyedoff. M., and Keusen.H.R. Collapse at theeastern Eiger flank in the Swiss Alps, Nature Geosci., 1(8), 531–535, 2008a.

[8]A.Abell´an, M.Jaboyedoff, T.Oppikoferand J.M.Vilaplana. Detection of millimetric deformation using a terrestrial laserscannerexperiment and application to a rockfall event.Natural Hazardsand EarthSystem Sciences,9, 365–372, 2009.

[9]Riegl.J., Studnicka.N., Ullrich.A. Merging and processing of laser scan data and high-resolution digital images acquired with a hybrid 3D laser sensor. In *Proceedings of CIPA, XIXth International Symposium*, Antalya, Turkey, 30 September–4 October, 2003.

[10]Abellán.A.,Vilaplana.J.M., Martínez.J. Application of a long-range terrestrial laser scanner to a detailed rockfall study at Vall de Núria (Eastern Pyrenees, Spain). Eng. Geol. 2006, 88, 136–148.

7th International Symposium on Digital Earth
Perth, Australia
23 - 25 August 2011

LANDSAT VEGETATION TRENDS AND LAND MANAGEMENT – GEOGRAPHICALLY IDENTIFYING THE EFFECTS OF LIVESTOCK NUMBERS ON VEGETATION IN DIRK HARTOG ISLAND

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ABSTRACT

Dirk Hartog Island, one of Australia's newest national parks has an interesting past as the location of the first European landing in Western Australia and more recently as a pastoral station. The opportunity this island presents to conserve endangered fauna and flora is one not to be missed. Effectively managing the transition of land use from the production of livestock to a conservation reserve requires knowledge of fluctuations in livestock rates and the impact on native and introduced vegetation across the entire island. Vegetation trend information derived from the Landsat satellite imagery archive [1] can provide this geographical and historical context.

The recent removal of grazing livestock has provided the prospect to correlate vegetation changes derived from Landsat imagery to known locality and numbers of livestock. Analysis of these data together will give perspective to the changes observed in the Landsat imagery across the island and provide precision and extension to anecdotal changes in stocking rates, watering point locations and dune movement. Satellite imagery can provide the important historical vegetation aspect to the new conservation managers, as the island is prepared for the reintroduction of rare animal species. Future planned capture of satellite imagery will enable the tracking of changes in vegetation cover and identify areas in requirement of remediation and investigation.

1. DIRK HARTOG ISLAND

Dirk Hartog Island creates the western edge of Shark Bay and is the largest island in Western Australia covering 620km^2 (Figure 1). The northern part of the island is the site of the first recorded European landing in Australia by Dutchman Dirk Hartog in 1616. In 1868 the island became a pastoral lease for running sheep, and this use continued until recent times, tourism operations started in the 1990's as well as the transition to national park which was completed in 2009 [2]. The Department of Environment and Conservation (DEC) is responsible for the management of the park and as such have initiated many actions to restore the ecology of the island. The size and remoteness of the island make satellite imagery a valuable tool in monitoring the transition of the island from pastoral land use to national park.

The restoration of Dirk Hartog Island aims to reconstruct the island's ecological integrity [3]. The removal of livestock will improve the amount of vegetation cover which provides habitat and protection for small marsupials and birds. The increase in vegetation cover will enable the reintroduction of marsupial species previously extinct on the island [4]. The island presents an opportunity to create a refuge for native plants and animals that were once widespread on the mainland.

The climate of Dirk Hartog Island is semi arid although it does receive more rain than the adjacent mainland. The landforms include rugged cliffs in the west and stable vegetated sand dunes inland. The vegetation ranges from tall open heath to low open heath with hummock grasses, hummock grassland and some low open shrubland. Areas heavily grazed have basically no native vegetation with introduced ephemerals dominating [5]. These areas occur more in the southern two thirds of the island where pastoral activities were focussed. The island supports many bird species and small marsupials. Some marsupial species such as the Banded-Hare wallaby were previously common on the island are now locally extinct, but there are plans to reintroduce such species where feral predators have been eliminated [3].

Figure 1: Dirk Hartog Island study area and locality map (NATMAP RASTER 250K 2002).

2. SATELLITE IMAGERY FOR MONITORING

The Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper plus (ETM+) satellite instruments together provide an over 20 year continuous archive of imagery at high spatial and spectral resolutions. The imagery has a swath of 180 kilometres, processed pixel size of 25 metres and three visible, a near infrared, two short wave infrared and a thermal band. This imagery archive provides the opportunity to monitor inaccessible and large geographic areas on a regular basis for a low cost.

For effective monitoring using satellite data image dates need to be processed to a level where pixels are georeferenced so they are comparable in space and calibrated spectrally so that pixel brightness values are consistent through time. Fortunately a rectified and calibrated archive of Landsat imagery exists covering the entire Australian continent. Australia's federal Department of Climate Change and Energy Efficiency administers the National Carbon Accounting System Land Cover Change Project (NCAS-LCCP) and the core dataset for this project is Landsat imagery. This processed imagery suitable for monitoring purposes is available at low cost through Geoscience Australia. The NCAS-LCCP archive contains dry season image data for the years 1989, 1991, 1992, 1995, 1998, 2000, 2002, 2004, 2005 and 2006. Annual dry season imagery for the years 2001, 2003 and 2007 to 2010 were purchased by DEC and processed to the same levels as the NCAS-LCCP data. Annual dry season imagery enables examination of changes within perennial vegetation without the influence of ephemeral vegetation present in the wet season.

2.1. Index Trend Images

To investigate the fluctuations in vegetation cover on Dirk Hartog Island using satellite imagery an index or band combination that responds in a linear scale to changes in vegetation cover is required. In this project the index used is Landsat 5 TM Band 3 plus Band 5. This index has been used extensively in the south west by the Land Monitor Project [6] and other areas across Western Australia by DEC. This index results in lower values or dark pixels representing denser vegetation cover and higher values or brighter pixels for sparser vegetation cover. To make the index data more intuitive the transformed pixel values are subtracted from 300 to make higher pixel values analogous with higher vegetation cover. The index is calculated for each available image date.

A technique to summarize the many dates of imagery into one graphical display is to calculate the linear and quadratic regressions and display these in a red, green and blue image [7]. This is referred to as an index trend image and can be used to geographically identify in red areas that have decreasing vegetation cover, blue as gaining vegetation cover and green as variable vegetation cover. This technique has been applied in the Shark Bay area previously to successfully identify areas of buffel grass invasion, overgrazing, fire scars and movement of mobile sand dunes [1]. Trend images have also been employed in the Land Monitor Project, where the index trend images are produced annually [8], in rangeland regeneration identification [9] and Wandoo tree decline in south west of Western Australia [10].

3. REMOVAL OF GRAZING LIVESTOCK

The removal of livestock has resulted in recovery of native fauna and vegetation in the semi-arid region surrounding Dirk Hartog Island. Feral goat control started on Bernier and Dorre Islands to the north of Dirk Hartog Island in the 1960's [11]. These islands have since become havens for many endangered marsupial species. Point Peron to the immediate east of the island initiated a feral goat removal program in the 1990's which has resulted in significant recovery of native vegetation and subsequent improvements in the small scrub bird population [12].

Aerial monitoring of the feral goats and sheep on Dirk Hartog Island occurred during August of 2008 and 2009. These surveys found concentrations of animals at the north west tip, surrounding the homestead and on the southern tip of the island. There is available water at these locations either in the form of natural seeps or watering points. The aerial survey was conducted in transects and in 2008 observed a total of 701 goats and 35 sheep and in 2009, 654 goats and 36 sheep.

Over the last five years there have been efforts to control livestock and feral goats and sheep. In 2007 the Lessee removed 4000 sheep. Since 2006 feral animals have been controlled to some extent with greater completeness over time, in 2006 only 89 feral goats were removed compared to 5475 in 2010. This increase in removal numbers heralds the change in management from some control of feral animals, to the removal of all, in aid of restoring Dirk Hartog Island's ecology.

4. TRENDS IN VEGETATION COVER

4.1. Investigating the Image Sequence

Selecting a time period to examine trends in vegetation cover may be arbitrary or defined by events such as fire, weather or changes in management. Ideally the condition of the vegetation in the first image in the sequence is well known and in this way the trend image display can be interpreted to show changes from a baseline year. When examining a number of time periods the vegetation trends in the period 2000 to 2010 displayed large areas of significant change. The north west tip of the island and around the homestead located halfway down the island are areas of large vegetation loss observed in this time period. This vegetation cover loss is attributed to goat and sheep grazing due to the availability of water at these sites. In the north west of the island there are sheer cliffs with caves containing seepages of water and there are water points near to the homestead.

Further investigation of the index values for each year in the image sequence illustrates the fluctuations in vegetation cover over time. This can be done easily in the software program VegMachine™ [13]. VegMachine™ provides a geolinked split screen to enable geographic selection of sites of interest which then can be queried to graph average pixel values for each image date. Using the trend image from 2000 to 2010, selection of areas in the north west of the island (red line in Figure 2) show that the cover varied in the 1990's but sustained vegetation cover loss occurred after 1998 and continued to decrease post 2005. This persistent loss over the last decade causes the area to be displayed as red in the trend image. Around the homestead the graph shows a continued loss in cover between 2002 and 2008 and then an increase in cover in 2009 and 2010 (green line in Figure 2). This is consistent with changes in management in this area as 4000 sheep were removed in November 2007. However the vegetation cover increase may not due to native species, field visits would determine if weed control is required. The loss and recovery of vegetation cover within a time period is displayed as green in the trend image this represents the positive quadratic regression. Areas of stable vegetation cover appear as black in the trend image, and when queried show small, probably seasonally driven changes in cover (dark line in Figure 2). Blue areas in the trend image indicate increases in vegetation cover in the time period and appear mostly in the south of the island.

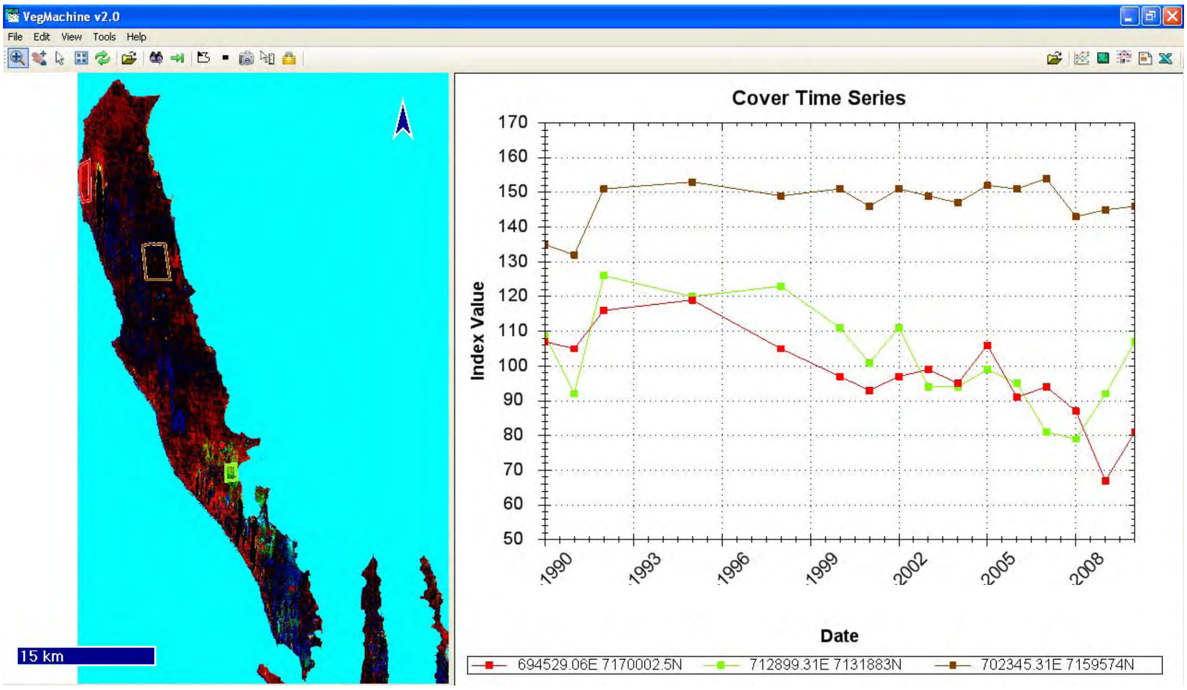

Figure 2: VegMachine™ display of trend image from 2000 to 2010 on left and graph of index values for all image dates 1989 to 2010 of queried areas on right.

4.2. Integration of Livestock Data and Trend Imagery

An operation to destroy feral stock was undertaken in February 2010. Animal numbers were recorded aerially with GPS flight lines and then aggregated on a grid cell basis to represent the actual location of feral animals rather than attributing long flight lines across the island (Table 1). This grid system aids in breaking up the island into manageable parts.

The Landsat 5 TM imagery for 2010 was captured on the 5th February, providing an appropriate date to observe vegetation cover impacts prior to the removal of this grazing stock. This image will afford a starting point to observe changes to the vegetation cover post feral stock removal. Comparing the aggregated goat data and the trend imagery requires a classification of the calculated trend image into useable categories. The linear trend can be broken up into five categories ranging from a large gain in vegetation cover to stable to a large loss in vegetation cover, the classification boundaries have been transferred from those used in the Land Monitor Project [7]. This allows area calculations of vegetation cover trend per grid cell which then can be compared to the feral goat numbers. Table 1 illustrates the comparison using the percentage area of each grid cell of increasing and decreasing vegetation cover over the period 2000 to 2010. This percentage is calculated using only the land area of the grid cell and aggregates the increasing and decreasing classes.

Grid cells E10 and E11 had active water points in 2007 to 2009 located in them which were reactivated in 2010, and these cells also have large numbers of goats and large areas of decreasing vegetation cover. The cells adjacent to these present the same scenario but do not contain water points. Thus the management of water points is essential in both the congregation of feral animals to aid removal and controlling the impact on vegetation cover. This application of contextual historical knowledge in conjunction with the processed satellite imagery means the impact of different management actions can be quantified on an annual basis. Other ancillary information such as vegetation types and landform could be included in the future to provide greater depth and aid management decisions.

The largest areas of decreasing vegetation are associated with the largest goat numbers as expected, however there are some anomalies that require further investigation. Grid cell B1 on the northern tip of the island has a large loss of vegetation cover, and although large numbers of goat were nearby none were destroyed in this grid cell. Whether this loss is likely to be due to the goats found adjacent or other causes such as vegetation type and rainfall could be established with reference to local knowledge. The southern part of the island displays the most variation in vegetation cover trends. This area includes mobile sand dunes, tourist areas, the pastoral homestead and was the location of the majority of the pastoral activities. Hence, the factors affecting the fluctuations of vegetation cover are more complex in this area. A quick increase in vegetation cover in this region may be more likely due to weeds introduced as pastoral feed rather than native vegetation recovery.

Effective communication of the relationship between the livestock numbers and the trend image information to the managers of the island is essential to the use of this technology. The table and mapping system shown in Table 1 is a simple, quick and effective method to convey a large amount of information. Presentation in a table format is useful for reporting requirements.

Field data is required to relate the magnitude of changes in vegetation cover observed by satellite to meaningful measures on the ground. Field data was collected in January 2011 so as to work towards this goal. Other projects undertaken by DEC have found this field data component essential in validating and extending the satellite imagery analysis [14, 15 and 16]. Relating the image analysis with field data aids in communicating the information derived with the land managers.

Grid Cell	Goat No. February 2010	Increase %Area Vegetation Cover	Decrease %Area Vegetation Cover
A1	34	2.34	81.01
A2	138	2.24	83.15
A3	511	3.11	85.85
A4	58	16.49	45.89
A5	44	16.07	35.65
B1	0	0.11	83.09
B2	0	2.23	42.34
B3	0	8.67	27.26
B4	9	19.93	17.38
B5	22	25.67	17.63
B6	66	13.03	28.26
B7	0	13.94	21.64
B8	0	9.10	46.43
C1	0	4.75	66.24
C2	0	4.64	49.27
C3	0	2.12	39.20
C4	0	5.41	14.32
C5	0	4.82	19.61
C6	0	10.41	21.83
C7	0	12.57	14.48
C8	0	16.23	35.58
C9	0	5.24	69.63
C10	0	9.49	62.01
D4	0	12.52	25.10
D5	0	4.66	66.28
D6	0	5.18	48.32
D7	0	2.17	40.70
D8	0	9.01	12.55
D9	28	17.09	43.96
D10	163	4.86	67.56
D11	122	5.37	76.72
D12	0	48.59	12.41
E7	0	5.63	60.82
E8	5	5.64	26.60
E9	60	0.96	77.63
E10	171	1.60	80.38
E11	271	5.88	64.28
E12	154	11.84	68.04
E13	2	20.87	52.26
F10	75	5.00	78.78
F11	15	5.95	60.17
F12	141	32.71	33.64
F13	37	10.34	55.83
F14	17	22.94	40.31
F15	0	64.55	29.29
G11	0	13.10	70.04
G12	12	26.97	31.36
G13	26	51.13	7.35
G14	30	40.33	10.23
G15	56	50.78	11.48
G16	8	57.94	12.87
H13	15	23.08	16.00
H14	43	8.85	35.10
H15	159	22.48	24.25
H16	16	46.08	13.78

Vegetation Trends Map Using Landsat Imagery 2000 -2010

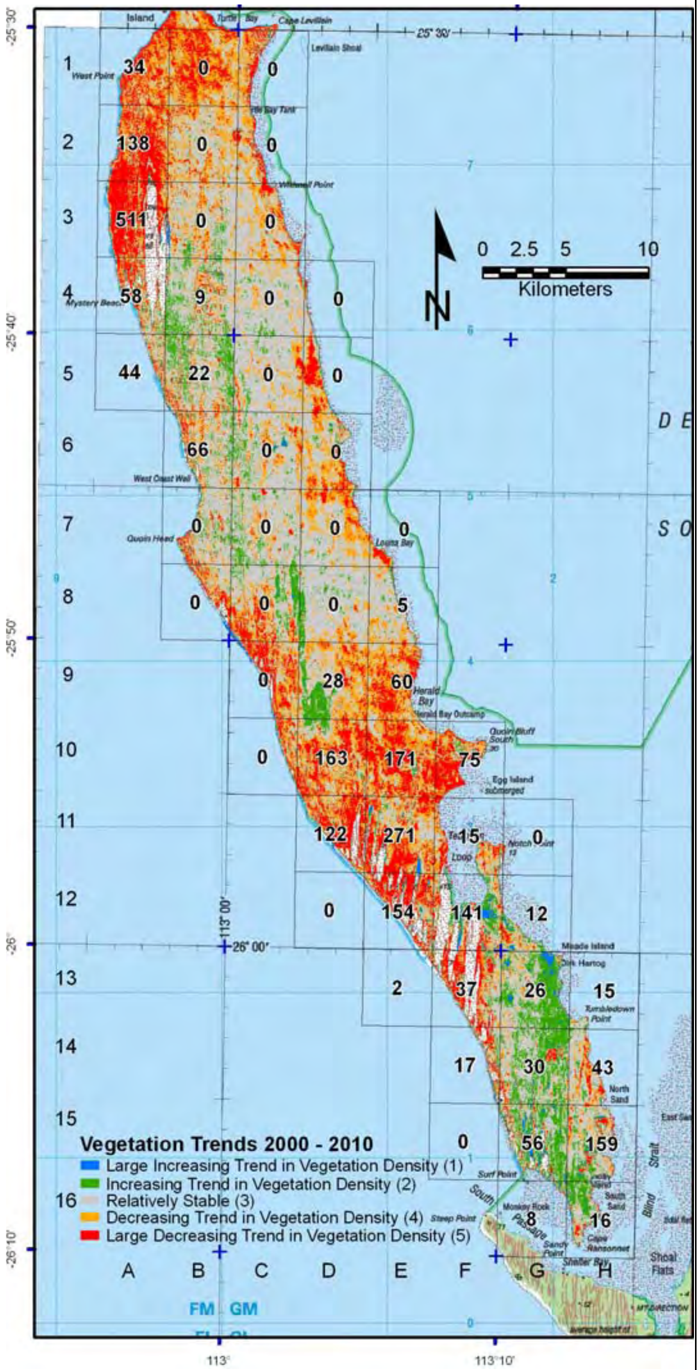

Table colour code
Red – Above 75% decreasing vegetation
Orange – 50-75% decreasing vegetation
Yellow – 25 – 50% decreasing vegetation

Table 1: Goats removed aggregated by a grid system compared with vegetation cover linear trend from 2000 to 2010 categorised.

5. CONCLUSIONS

An issue in this analysis is the recording of feral animal numbers and locations. These were not always captured in a consistent and geographically sensible way. With greater understanding of the technology and the requirements of effective application of the counts data the method of recording these data has and will continue to improve. Monitoring into the future relies on suitable Landsat or comparable imagery being available in the dry season. With the failure of Landsat 5 and missing data in Landsat 7 imagery, two date fill in Landsat 7 imagery [17] will be required until the next Landsat mission starts capturing imagery. This mission is currently scheduled for launch in December 2012. The two date fill in data is not ideal if there is too long a gap between image dates or a weather event, as differences within an image can make comparisons with previous years difficult.

Other applications of this analysis are the management of fuel loads for fires, weed invasions and dune movement. Along with the expected increase in vegetation cover will be the requirement to actively manage the fuel loads for fires. Quantifying the vegetation cover will help determine the fire risk. With less grazing animals on the island to consume weed species there is a possibility they will spread into degraded areas. Field visits to areas indicated by the trend image to be quickly increasing in cover will determine if this is the case. There are several dune blowouts that expand by metres a year on Dirk Hartog Island that can be monitored by annual imagery captures.

Investigating the historical changes in vegetation cover on Dirk Hartog Island with satellite imagery provides a comprehensive geographic view of the effect of land management actions. When this information is combined with other location based information such as the location of feral animals the ability to quantify and report on changes in management becomes more complete. Future acquisitions of imagery, calculations of trends and combination of ancillary data will aid in locating areas of sustained vegetation recovery for reintroduction of endangered species.

6. ACKNOWLEDGEMENTS

We would like to thank Brett Fitzgerald, Ross Mack, Colleen Sims, Winston Kay and Emma Jayne Richardson of the DEC Denham and Geraldton offices for the impetus and local knowledge for this project. Thanks also to Suzanne Furby and Jeremy Wallace at CSIRO Mathematical and Information Sciences in Floreat.

7. REFERENCES

[1] Wallace J.F., Behn G., Furby, S.L.: Vegetation condition assessment and monitoring from sequences of satellite imagery, *Ecological Management and Restoration*, Vol. 7, S1, pp 31-36 (2006).

[2] Thomson-Dans C.: Dirk Hartog Island: inscribed in history, *Landscope*, Vol. 23, No. 2, pp. 32-38 (2007).

[3] Department of Environment and Conservation Western Australia: Shark Bay Terrestrial Reserves and Proposed Reserve Additions Draft Management Plan, *Conservation Commission of Western Australia*, (2007).

[4] Burbidge A. A., George A. S.: Report on a visit to Dirk Hartog Island with recommendations on the re-establishment of marsupials, *Department of Fisheries and Fauna Western Australia*, pp. 31 (1973).

[5] Burbidge A. A., George A. S.: The flora and fauna of Dirk Hartog Island, Western Australia, *Journal of the Royal Society of Western Australia*, Vol. 60, pp. 71-90 (1978).

[6] Caccetta P. A., Campbell N. A., Evans F. H., Furby S. L., Kiiveri H. T., Wallace, J. F.: Mapping and monitoring land use and condition change in the South-West of Western Australia using remote sensing and other data, *Proceedings of the Europa 2000 Conference*, Barcelona (2000).

[7] Furby S., Zhu M., Wu X., Wallace J.F.: Vegetation Trends 1990-2008 South West Agricultural Region of Western Australia, *Land Monitor II Project*, CSIRO MIS, Available from http://www.landmonitor.wa.gov.au/reports/landmon_II/LM2008_VegTrend_1990_2008.pdf (2008).

[8] Land Monitor: Land Monitor A project of the Western Australian Salinity Action Plan supported by Natural Heritage Trust, http://www.landmonitor.wa.gov.au, (2011).

[9] Curry P., Zdunic K., Wallace J., Law J.: Landsat monitoring of woodland regeneration in degraded mulga rangelands: implications for arid landscapes managed for carbon sequestration, *Proceedings 14th Australian Remote Sensing and Photogrammetry Conference*, Darwin, (2008).

[10] Garkarklis M., Behn G.: Assessment of *Eucalyptus Wandoo* (Wandoo) and other tree canopy decline using Landsat Trend Analysis, *Department of Environment and Conservation Western Australia*, p. 15 (2009).

[11] Department of Fisheries and Fauna Western Australia: Goat eradication: Bernier Island, *Swans*, Vol. 2, pp. 60-61 (1971).

[12] Shepherd R.: Eradication of feral goats and sheep, Peron Peninsula, Western Australia: progress report, January 1996: Feral Pests Program, *Australian Nature Conservation Agency project number 48*, p. 17 (1996).

[13] Karfs R.A., Daly C., Beutel T.S., Peel L., Wallace J.F: VegMachine – Delivering Monitoring Information to Northern Australia's Pastoral Industry, *Proceedings 12th Australasian Remote Sensing and Photogrammetry Conference*, Fremantle, Western Australia, (2004).

[14] Behn G., McKinnell F. H., Caccetta P. A., Vernes, T.: Mapping forest cover, Kimberley Region of Western Australia, *Australian Forestry*, Vol. 64, No. 2 pp. 80-87(2001).

[15] Zdunic K., Behn G.: Exploiting time sequences of satellite imagery to monitor landscape aspects, *Proceedings Spatial Sciences Conference*, Adelaide, South Australia (2009).

[16] Behn G., Zdunic K., Kinloch J., Wilson B.: Development of Remotely Sensed Vegetation Cover Index and Vegetation Cover Trends Analysis, Department of Environment and Conservation and Gnangara Sustainability Strategy, Western Australia, p. 23 (2009).

[17] Furby S.L., Wu X.: Evaluation of alternative sensors for a "Landsat-based" monitoring program, *Proceedings 13th Australasian Remote Sensing and Photogrammetry Conference*, Canberra, Australian Capital Territory, (2006).

ISBN: 978-0-646-57316-8

Supported by

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