



PROJECT MILESTONE REPORT

Program:	National Program for Sustainable Irrigation		
Project Number:	UNS5127		
Project Title:	Quantifying surface water groundwater exchange using thermal and chemical measurements		
Research Organisation:	University of New South Wales		
Principal Investigator:	Ian Acworth		
Project Start Date:	05/09/08	Project Completion Date:	30/11/11

Milestone Report Title:	Final Milestone		
Milestone Number:	6		
Milestone Due Date:	15/12/11	Date Submitted:	14/12/11



General Project Information

1. Project Objectives

This project seeks to design, develop and test an integrated measuring tool that can be installed and recovered from the bed of streams and rivers. The tool will comprise temperature and water level loggers and newly developed probes to monitor fluid electrical conductivity, the concentration of chloride in the water and oxygen levels (as a measure of water quality).

2. Location

Multiple tools will be deployed at selected sites in streambed sediments under variable field conditions in the Maules Creek and in the Namoi River, NSW. One site in particular will be central to the field work: At Elfin Crossing on Maules Creek an experimental transect of 26 shallow and 3 deep piezometers has been installed. It is envisaged that this transect will provide an excellent field testing ground for the tools, since the 3D flow pattern surrounding the creek can be assessed by pressure transducers in the piezometers. Although the investigations will provide insight in the hydrogeology and water exchange at the suggested site, more importantly it will generate generic process understanding and improved methodology for deriving streambed water exchange rates of wider geographic applicability.

3. Outcomes

This project will develop field equipment and a proven scientific methodology that will quantify surface water loss to groundwater below surface water bodies and therefore contribute to the mapping of the many and complex connections and interactions between groundwater and the surface water - dams, lakes, rivers, wetlands. The project will allow development of a prototype that should be capable of commercialisation.

As a result of this project, there will be much improved knowledge and understanding of a process that can, in turn, inform policy development and water allocation decisions. The new knowledge will allow development of consultancy services based upon deployment and interpretation of the sondes.

In addition field data acquired by the sondes could provide much needed independent confirmation of various other modelling studies.

4. Target Audience for the research

The audience of this research work will span from irrigators over regional NRM groups, government policy makers, regional water planners, to the international scientific community in the field of hydrology and hydrogeology. Irrigators and regional NRM groups, government policy makers, regional water planners will be targeted by workshops, NPSI factsheets and bulletins, and publications in professional journals such as Irrigation Australia Journal. The scientific community will be addressed by publications in peer-reviewed International Journals.



Milestone Report Information

5. Milestone Requirements and Deliverables

1. Milestone report using LWA template and must include reporting on the activities listed below.
2. Monitoring and evaluation report.

6. Project Progress & Milestone Achievements

The milestone achievements to date include:

- a) Analysis and interpretation of experimental laboratory data has been completed for homogeneous coarse sand in the advanced hydraulics experiment facility. The mathematical validity of estimating water flow velocities using the heat method, in particular with relation to the dispersion of heat, has been experimentally verified using solute breakthrough curves.
- b) Prototype temperature arrays were field tested at Elfin Crossing in Maules Creek against water flow rates estimated by the 222-Radon disequilibrium method. The methods were found to compare favourably.
- c) A new computational method to explicitly calculate time series of water flow velocities and thermal diffusivity have been developed (McCallum et al., Geophysical Research Letters, submitted).
- d) Three journal papers with direct relevance to the project have been submitted to A* international scientific journals. One is in revision and two are in review (see publications for details). Confidential drafts are available upon request.
- e) Major project findings and outcomes were presented to the Australian hydrogeological community at a combined workshop for New South Wales Office of Water (NOW) hydrogeologists and a regional IAH meeting in Tamworth on 19 July 2011.
- f) The scientific results of the project were presented in three talks at the annual American Geophysical Union (AGU) meeting in San Francisco, 5-9 December 2011. The annual AGU meeting is the largest earth science meeting in the world. A majority of the international experts on using heat as a tracer were present at these presentations.
- g) Finally, Gabriel Rau submitted his PhD dissertation titled: "Experimental analysis of heat as a tracer for the quantification of thermal dispersion and water flow in sand" on the 30th of November 2011 (ahead of time) for examination.

The activities to date:

WRL advanced hydraulic testing facility

One of the main tasks during this reporting period has been to finalise the analysis and interpretation of the vast amount of experimental data from the advanced hydraulic testing facility and the field.

The ability of using sinusoidal temperature fluctuations to quantify water flow through saturated sand was tested experimentally under controlled hydraulic conditions. Comprehensive experiments were conducted with a range of different flow velocities through the uniform coarse sand (for summary see Table 1). The area heat source was used to simulate sinusoidal temperature fluctuations analogously to the field observations of daily perturbations in shallow sediment systems. For each flow velocity a heating signal of at least 5 periods in length was generated. The pore water velocity was also measured by tracking the movement of a solute slug that was injected into the same flow field. This was conducted using the same methodology as outlined in Milestone report 5.

The heat tracing theory allows the calculation of water velocity from the characteristic damping and shifting of the temperature sinusoids with depth and flow velocity. Tests were conducted with sinusoids having different periods to avoid edge effects that may occur from the experimental setup. To extract the sinusoidal amplitudes and phases, the induced heating signal and spatial temperature response



within the sediment were recorded (Fig. 1) with approximately 29 specialised temperature sensors (high resolution minimal impact). The temperature data contains a significant temperature trend which requires de-trending before velocity calculation. A simple linear de-trending scheme was used in order to extract the sinusoidal coefficients (Fig. 2).

For each flow velocity, temperature data from different combinations of temperature probes can be evaluated. These pairs must be arranged vertically in the experimental space. Amplitude and phase data for all velocities and temperature sinusoids were computed. From these data the amplitude damping and phase shifting was calculated. Furthermore, these values are dependent on the experimental Darcy velocity which enables the calculation of velocities for all possible sensor combinations and experiments. These temperature derived velocity results were compared to solute derived values (Fig. 3). For these calculations the thermal parameters, as previously determined by the point source experiments (see Milestone report 5), were used.

This set of experiments was aimed at fundamentally verifying the capability of heat as a tracer in the field but under ideal conditions. The results confirmed the suitability of the methodology commonly used in the field. Velocities could be quantified with an accuracy of approximately 20% using heat as a tracer compared to solute derived velocities. This is a certainty that by far outperforms traditional hydraulic assessment methods.

Table 1: Overview of experimental runs conducted in the reporting period using the area heat and point solute source.

Solute Velocity	Heating Grid Output		Temperature Amplitude at Heating Grid		Experiment	
	EC1-3	Peak Power	Sinusoid Fit	Location 1	Location 2	Period
m/d	W	R ²	°C	°C	S	-
0	54.7	0.999986	0.952	0.955	36000	601
0.125	65.2	0.999988	1.062	1.065	32400	541
0.374	65.5	0.999988	0.942	0.942	25200	421
0.768	87.3	0.999992	1.159	1.158	21600	361
1.066	98.2	0.999993	1.077	1.074	14400	241
1.438	174.4	0.999996	1.913	1.903	14400	241
2.011	141.7	0.999995	1.336	1.313	10800	181
2.407	326.6	0.999998	2.957	2.820	10800	181
2.472	162.5	0.999996	1.195	1.185	7200	121
3.332	184.1	0.999997	0.938	0.950	3600	121
4.376	219.3	0.999997	1.084	1.069	3600	121
5.739	324.0	0.999998	1.122	1.117	1800	91
6.844	288.2	0.999998	0.983	0.965	1800	91
7.504	356.3	0.999998	1.158	1.106	1800	91
8.919	410.2	0.999999	1.242	1.152	1800	91
11.098	504.6	0.999999	1.156	1.077	900	91
12.983	558.2	0.999999	1.191	1.061	900	91
15.142	643.8	0.999999	1.259	1.078	900	91
16.876	652.0	0.999999	1.191	1.002	900	91
18.608	731.0	0.999999	1.247	1.024	900	91

The results indicate that heat as a tracer delivers good results for Darcy flows that are smaller than approximately 3 m/d. However, further assessment of the flow field using colour dye also revealed that there is increasing and significant preferential flow through the well sorted sand with increasing flow velocities (Fig. 4). This observation leads to the following conclusions:

- Increasing variability of the heat derived Darcy velocity with increasing experimental flow as detected with a high spatial variability of sensor responses in the sand



- A discrepancy between solute and heat velocities of approximately 12% for amplitude and approximately 20% for phase derived velocities
- Horizontal temperature gradients introduced by the spatially variable flow field which lead to significantly enhanced thermal spreading

The spatial variability of the flow field is a surprising phenomenon given the homogeneous nature of the sand. Preferential flow is expected to significantly increase with more realistic sediments. Therefore, it is recommended that further experimentation be conducted with different types of sediment in order to verify the influence of realistic sediment texture on velocities quantified using heat as a tracer.

The current results are based on ideal conditions and therefore form a foundation for future work. Results obtained from these experiments have significant implications for the application of heat as a tracer in the field. These results were analysed in detail and presented in a journal paper submitted to one of the best international scientific journals in this field (Water Resources Research).

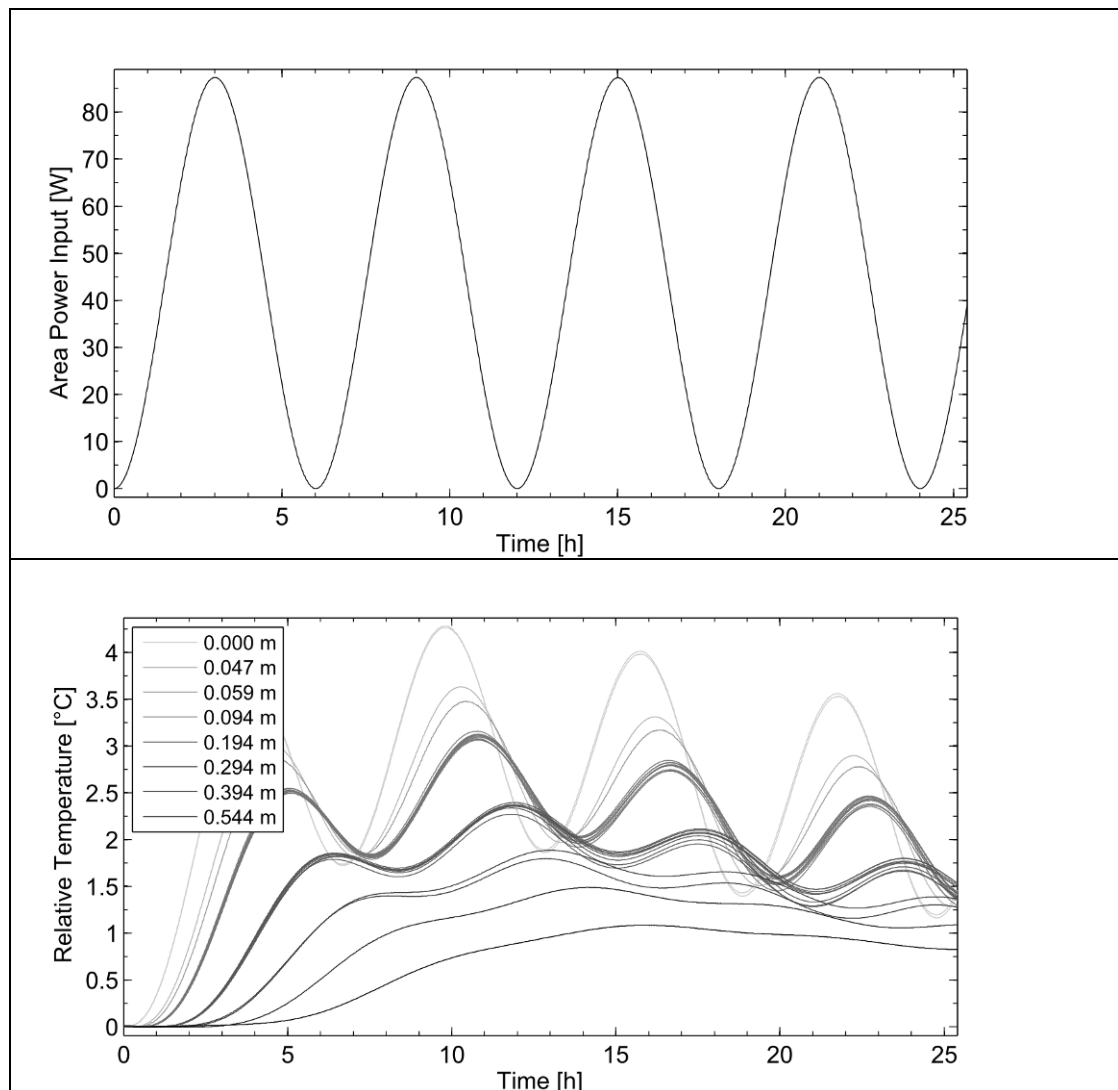


Fig. 1: Top row: Example of sinusoidal heating from the areal source (grid) inducing a sinusoidal heat signal in order to simulate diel thermal forcing in the shallow subsurface of water bodies. Bottom row: Temperature response to sinusoidal heating at different distances from the heat source.

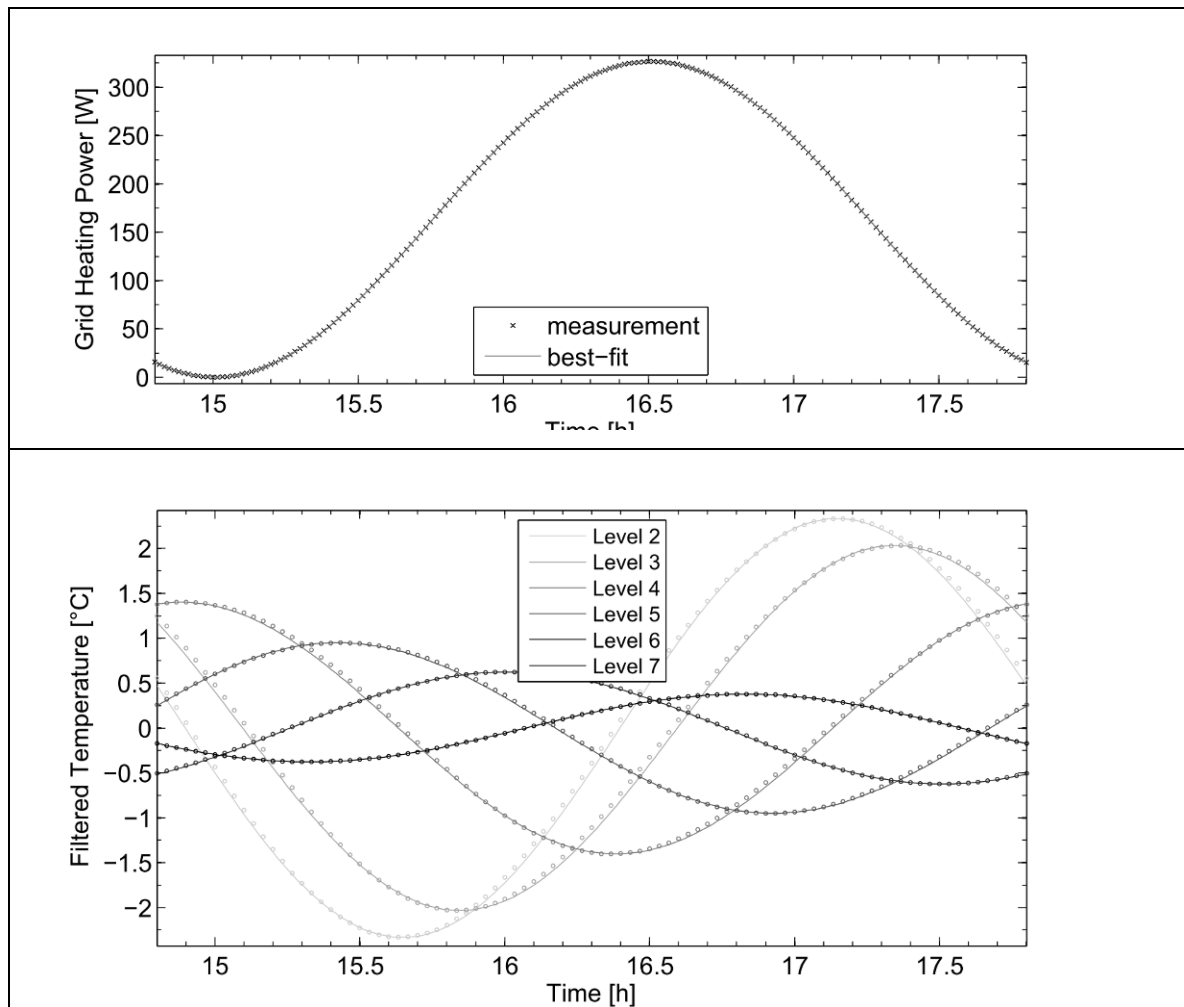
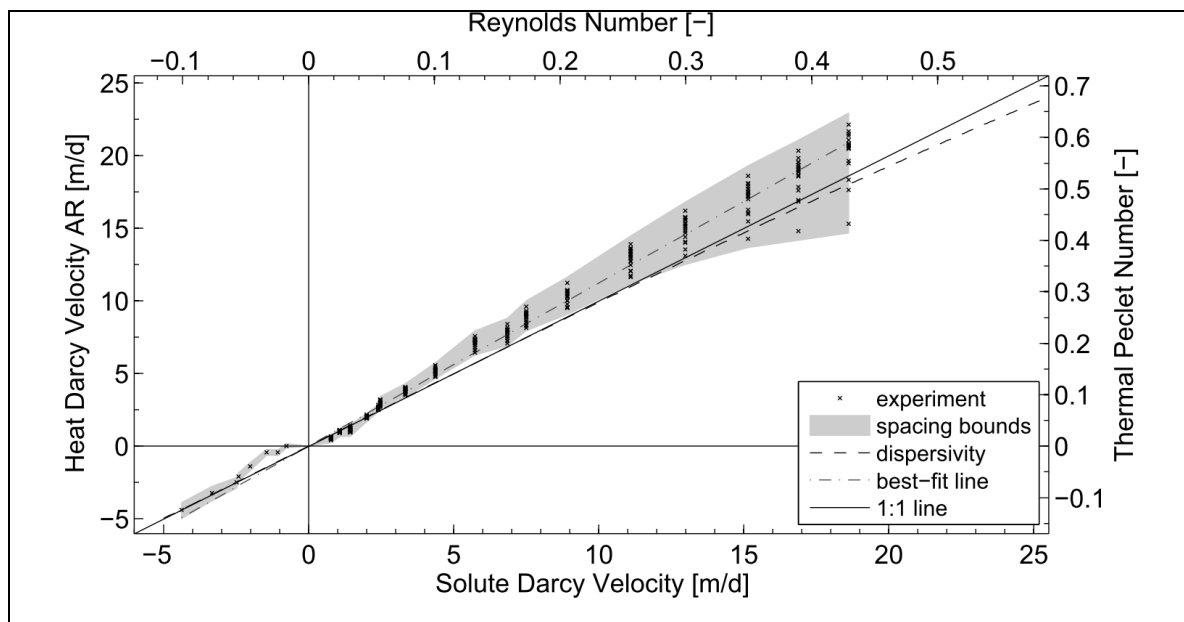


Fig. 2: Top row: Example of a measured temperature response for a 3 hour period including the best fit to a sinusoid. Bottom row: Temperature response to the heating measured at different distances and corrected for the underlying trend.



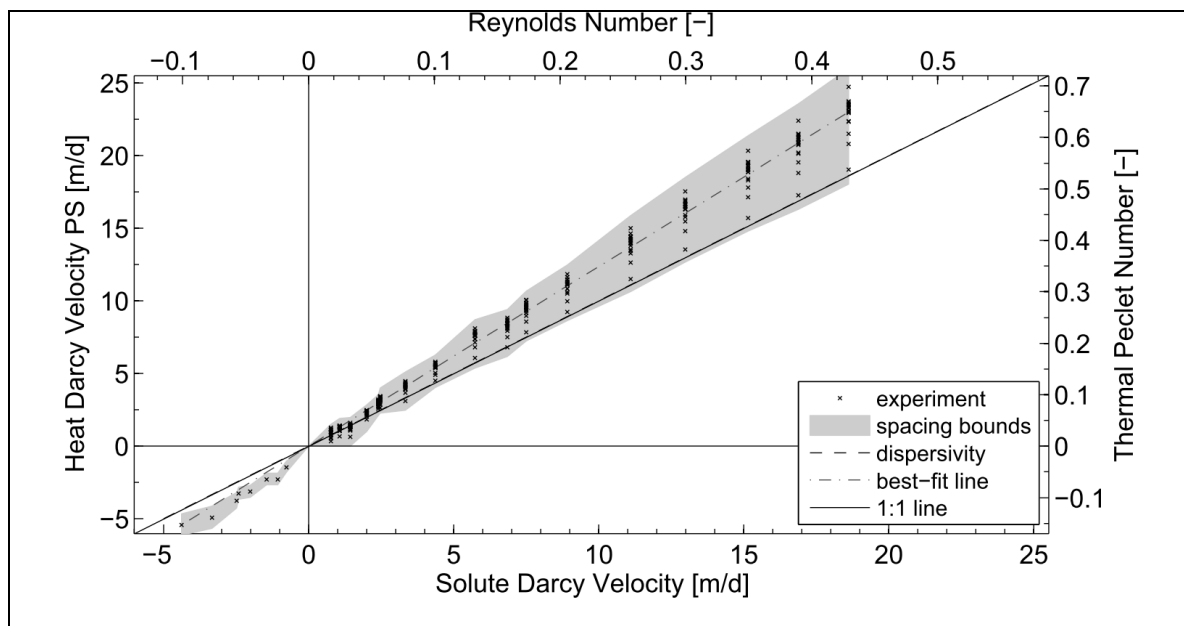


Fig. 3: Top: Velocities from temperature amplitude damping versus solute slug derived flow velocities. Bottom: Velocities from phase lag versus solute slug derived flow velocities. Error bounds (grey area) originate from the uncertainty in the sensor locations and thus sensor pair spacings (+/- 5 mm).

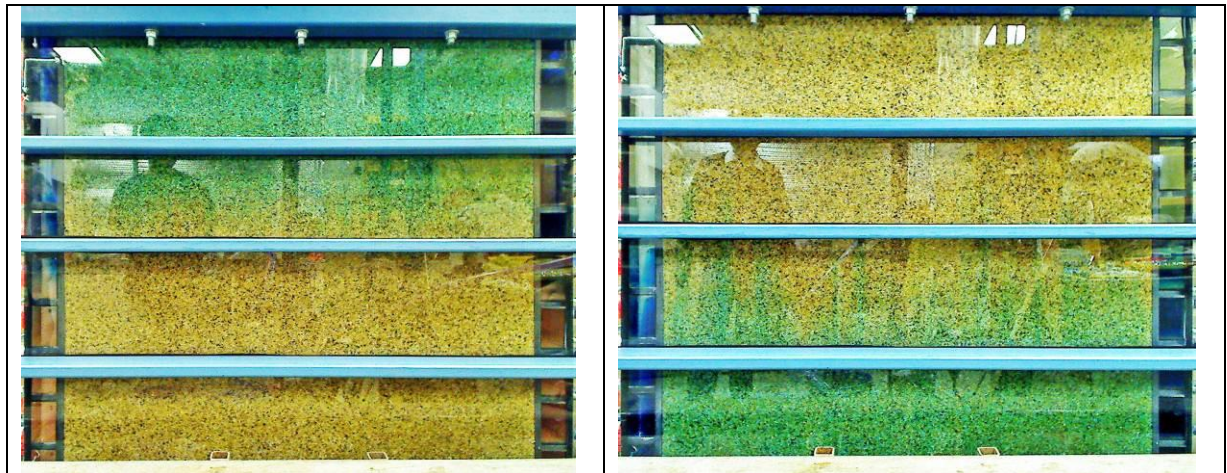


Fig. 4. Colour dye experiments to visually characterise the flow field in the sand.

Prototype streambed data – validation of flow rates derived in the field

Radon (^{222}Rn) data obtained during the October 2009 Maules Creek Elfin Crossing geochemical sampling campaign has been used to calculate groundwater residence times. These residence times can be converted to flow velocities which can be compared to the flow velocities derived using the heat tracing method in the streambed. Figure 5 shows dissolved Rn activities measured in the surface water as well as in the piezometer transect. The radon data demonstrates a zone of low radon activity below the creek indicating infiltration of surface water with a low radon activity. According to Hoehn and von Gunten (1989), Rn activities will approach secular equilibrium (late times in Figure 6) at large groundwater residence times where the radioactive decay balances the Rn emanation from the sediment. If this secular Rn activity is known, then Rn activities at disequilibrium, (i.e. at early times < 15 days, the steep part of the curve in Figure 6), can be used to estimate the groundwater travel times or residence times: $C_t = C_0 \cdot (1 - e^{-(t/T_{1/2})})$. Figure 7 shows the residence times for an assumed secular equilibrium Rn activity of 60.2 Bq/L (based on Rn activities in the deeper bores). Further assuming linear flow paths from a point in the streambed to the piezometer screens, the Rn travel times can be converted into a Darcy flow velocity: $v = (1/n) \cdot dx/dt$. These Darcy flow rates range from 0.03 to 0.43



m/d and are spatially quite variable, as can be seen in Figure 8. This could be due to heterogeneities in the aquifer and the streambed. However, the values compare favourably to the temperature derived velocities which, at the time of the radon measurements, were found to be around 0.4 m/d (see Fig. 9). A major limitation to this comparison is that, while we have continuous time series from the streambed temperature data we only have radon measurements at discrete points in time. Nevertheless the rough agreement gives us confidence that our temperature method delivers the right results.

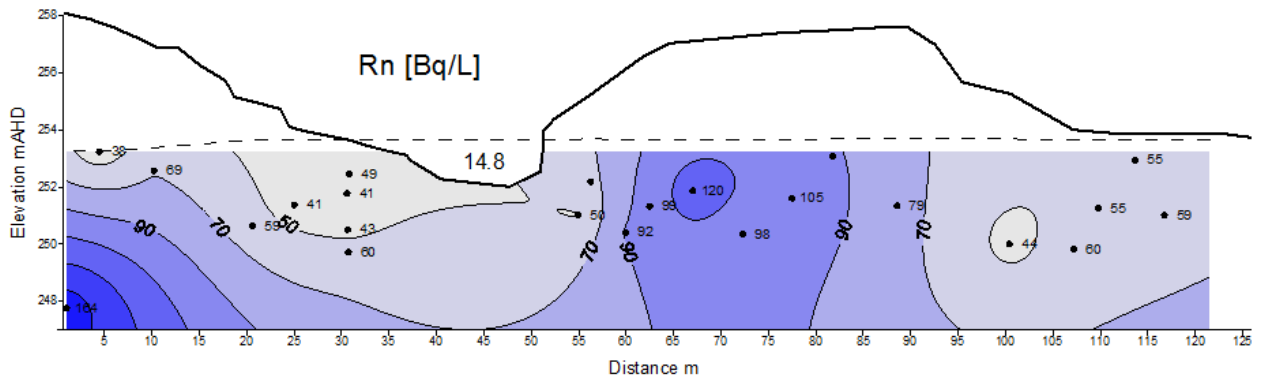


Fig. 5. Interpolated surface water and groundwater ^{222}Rn activities (Bq/L) as measured at the Elfin Crossing transect (Maules Creek).

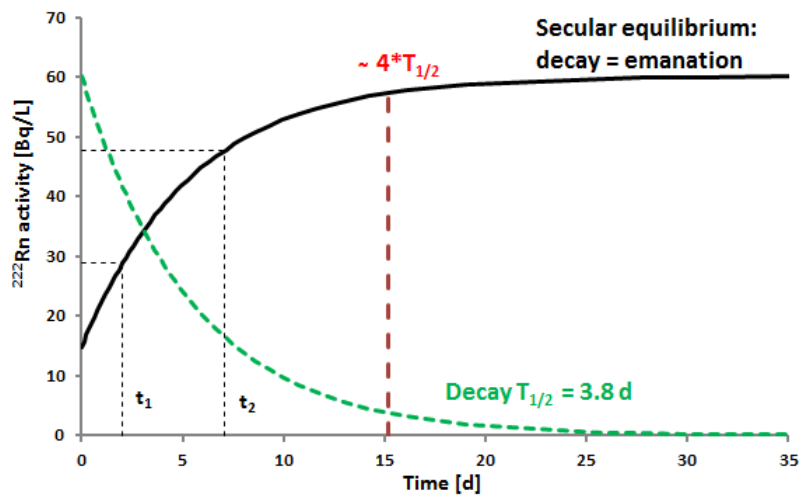


Fig. 6. ^{222}Rn activities as a function of decay and emanation, and the estimation of residence times.

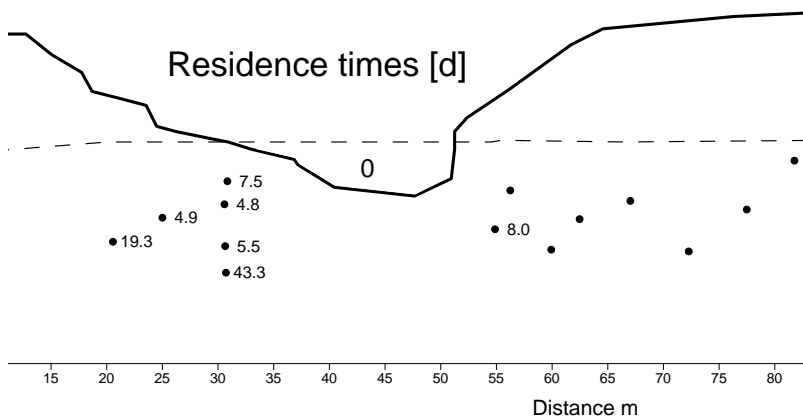


Fig. 7. Groundwater residence times (days) derived from radon activities for an assumed secular equilibrium Rn activity of 60.2 Bq/L.

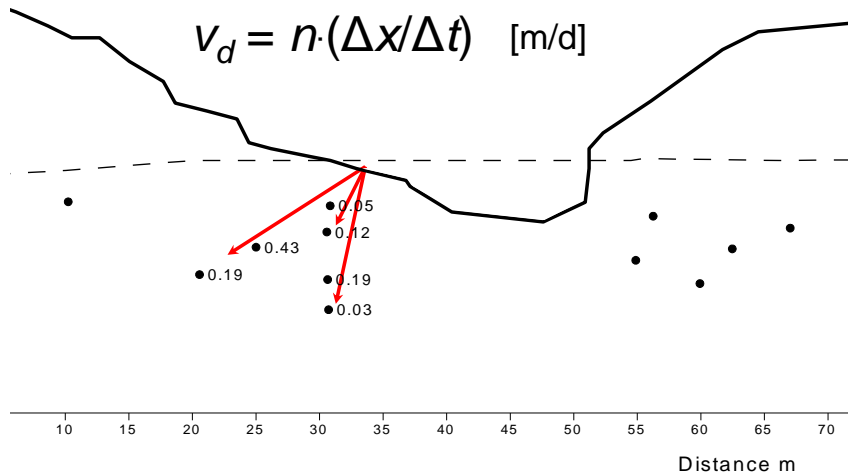


Fig. 8. Groundwater Darcy flow velocities (m/d) derived from the radon residence times assuming a straight travel part from one point in the streambed.

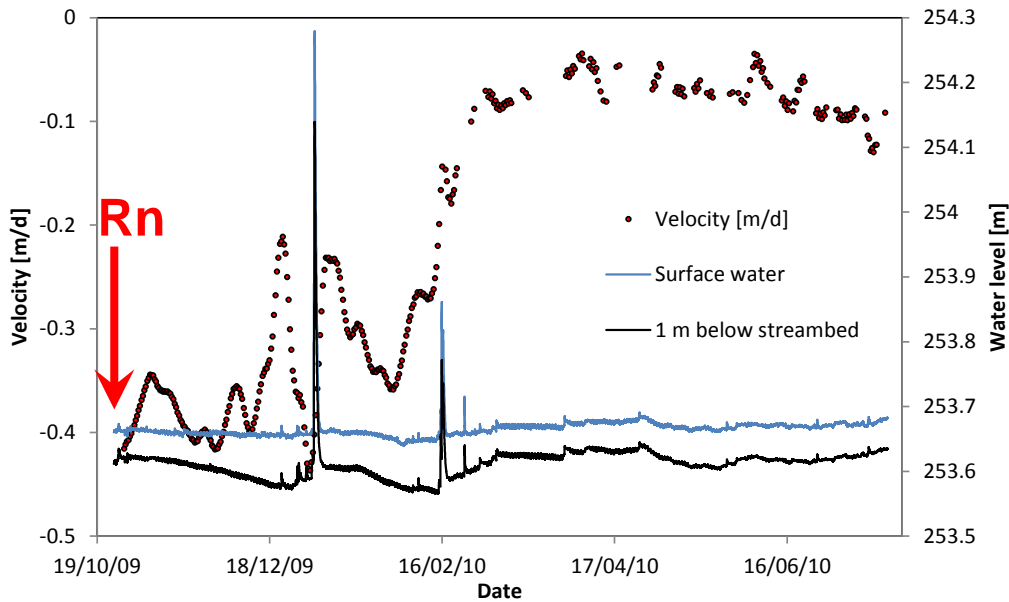


Fig. 9. Streambed vertical velocities from temperature data measured at Elfin Crossing (Maules Creek) as well as surface water and streambed heads. The radon data were obtained at the beginning of the period as indicated by the arrow.

Field results from The Namoi River

The six prototype temperature arrays which were installed in the Namoi River between Boggabri and Narrabri were retrieved, processed and analysed in the previous reporting period (Milestone report 5). The temperature derived velocity data from this deployment are now being used to analyse temporal variability in surface water losses from the Namoi River as part of work in the Cotton CCC by PhD student Andrew McCallum. The data show some interesting temporal variability in the velocities during dam releases and floods. At one particular site, the streambed is losing most of the time and particularly when the river is in flood. These data highlight the significance of these events for the recharge of the underlying aquifer and for changing the streambed properties. Part of this work has just been submitted to the journal *Geophysical Research Letters*, and another manuscript will be drafted and submitted over the next 6 months using temperature data collected during this project.



7. Next Steps

The project is officially completed with this report being the last Milestone report. However, the research using heat as a tracer has gained momentum and much of the theoretical and practical development work in this project will be continued as part of the NCGRT in the years to come.

Fieldwork activities

Field activities using heat as a tracer will be continued over the next 3 years within the NCGRT at Elfin Crossing in Maules Creek, the Tambo River in Victoria as well as several other field sites around the country.

WRL advanced hydraulic testing facility

Experimentation using the Magic Box will be continued over the next 3 years within the NCGRT. The focus of this future work will be on the effects of various degrees of sediment heterogeneity on the reliability of our method as well as fundamental understanding of heat transport in heterogeneous porous media. This research will help answering why field temperature data sometimes give results that are impossible to interpret. Furthermore, it will help to determine the limitations of using certain mathematical solutions for deriving flow velocities from field temperature data.

Publication and dissemination of results:

Several international journal publications with direct relation to methods developed and data collected during this project will be written, submitted and reviewed over the next year (Please see manuscripts in preparation in the publications list below under section 11).

Results and lessons learnt from the project will be incorporated into presentations for the Surface Water Groundwater Interactions workshop organized by CSIRO and NWC and the annual Cotton Science Forum both planned for March 2012.

Milestone deliverables in the upcoming reporting period

None, since the project is officially terminated.

8. Linkages with other research

As a direct consequence of our work to date on using heat as a tracer, heat tracing is a subprogram (P1C) in the NCGRT (National Centre for Groundwater Research and Training). The Elfin Crossing site at Maules Creek has been made an official field research site for program 1 and program 3 of the NCGRT. In this connection the existing groundwater piezometer transect at Elfin Crossing has been augmented with a pumping bore and additional piezometers financed by the Groundwater EIF Super Science funding (DIISR). This experimental setup will allow us to study the impact of groundwater abstraction on stream flow in a controlled way. The temperature tools developed in this NPSI project will play a central role in monitoring the direct impact of groundwater pumping on water exchange through the streambed. The NPSI project will benefit from the added information of dynamic flow patterns for the field testing of the streambed tools. PhD student Andrew McCallum, working on a project for the Cotton CCC, is currently using the temperature data and derived flow velocities from the Namoi River to support his research on surface water ground interactions and the effects of groundwater abstraction. It is beyond doubt that the work in the current project will inspire and define future project work on heat under the NCGRT with continued fieldwork in the Namoi Valley as well as at other new field sites. Six temperature arrays have already been installed in the Tambo River in Gippsland, Victoria in collaboration with researchers from Monash University. Currently under consideration is the Macquarie River at Wellington and the Ti-Tree basin in NT with NCGRT collaborators.

9. Issues of Concern / Risks

During this reporting period we have not experienced any significant delays. In fact our drafting of research papers went beyond our expectations for the current reporting period.



10. Opportunities

The heat research in NCGRT commenced in November 2011 to coincide with the final phase of this NPSI program and we have signed up two post-doctoral fellows to continue the work with the Magic Box and in the field.

The experiment facility will be of further use in regards to understanding fundamental processes in real streambed sediments beyond the scope of this project in the future. The streambed tools have been reinstalled at several sites for continuous monitoring of hydrological processes. Based on discussions at the 2011 annual AGU meeting in San Francisco, possible collaborations are currently being discussed with researchers from the Helmholtz Center for Environmental Research (UFZ), Leipzig, Germany. Further scope for collaboration with Monash University was discussed with Professor Ian Cartwright.

11. Impact data for knowledge, adoption and promotional activities undertaken

The current reporting period has seen much activity in terms of dissemination of results and outreach. The practical aspects and usefulness of methods developed as part of the NPSI Heat project was presented by Gabriel Rau at a joint workshop for NSW Office of Water (NOW) and IAH regional meeting on 19 July 2011 in Tamworth. The meeting was attended by NOW staff from several offices around the state as well as regional consultant Hydrogeologists. The overall feedback was very positive. The major response was in regards to the novelty of using temperature measurements for the quantification of water flow in shallow sediments. The advanced computational toolbox developed as part of this project was promoted at the workshop.

The scientific results and implications of our findings were presented in three talks by Gabriel Rau, Andrew McCallum and Martin Andersen at the annual 2011 AGU meeting in San Francisco. A cumulative list of publications and presentations are included below.

Cumulative communications

Material being prepared or presented in the current reporting period is **marked in red**.

Journal papers:

- **Andersen, M. S., G. C. Rau, A. M. McCallum, and R. I. Acworth (in prep), Comparison of streambed seepage rates quantified with temperature data, 222-Radon and Darcy's law, J Hydrol.**
- **McCallum, A. M., M. S. Andersen, G. C. Rau, and R. I. Acworth (submitted), A novel method to calculate in-situ riverbed seepage and thermal diffusivity from temperature data, Geophysical Research Letters.**
- **Rau, G. C., M. S. Andersen, and R. I. Acworth (in prep), On the modelling and application of heat as a tracer for the quantification of water flow in sediments: A Review, Earth-Science Reviews.**
- **Rau, G. C., M. S. Andersen, and R. I. Acworth (in review), Experimental investigation of the thermal dispersivity term and its significance in the heat transport equation for flow in sediments, Water Resour Res.**
- **Rau, G. C., M. S. Andersen, and R. I. Acworth (submitted), Experimental investigation of the thermal time-series method for surface water-groundwater interactions, Water Resour Res.**
- Rau G., Andersen M.S., McCallum A. Acworth R.I. (2010): Analytical methods that use natural heat as a tracer to quantify surface water-groundwater exchange, evaluated using field temperature records. Hydrogeology Journal. 18(5): 1093-1110. DOI 10.1007/s10040-010-0586-0.

Report for the NWC Groundwater Forum in Canberra:

- Andersen M.S., Rau G., Acworth R.I. (2009): Quantifying surface water groundwater exchange using thermal and chemical measurements (UNS005127). In Groundwater Action Plan NWC Groundwater Forum 24-25th November 2009 - Project Status Report.

NPSI publications:

- Quantifying vertical water flow using natural heat as tracer. NPSI fact sheet (web page).
- Methodology for measuring Vertical Water Flow Using Natural Heat as Tracer. NPSI research Bulletin (draft web page).
- National Program for Sustainable Irrigation: Use of natural heat as a tracer to quantify water flow in shallow saturated unconsolidated hydrogeological systems. Progress Report 2010.



Conference abstracts and presentations:

- **Andersen, M. S., G. C. Rau, A. M. McCallum, and R. I. Acworth (2011), Redox processes and arsenic release in the streambed of a semi-arid losing stream, paper presented at AGU Fall Meeting 2011, San Francisco, USA, 5-9th Dec 2011.**
- **Andersen, M. S., G. C. Rau, A. M. McCallum, K. Meredith, and R. I. Acworth (2011), Redox Constraining water fluxes through the streambed of a semi-arid losing stream using natural tracers: heat and radioisotopes, paper presented at AGU Fall Meeting 2011, San Francisco, USA, 5-9th Dec 2011.**
- **Andersen, M. S., G. C. Rau, A. M. McCallum, K. Meredith, and R. I. Acworth (2011), Groundwater recharge and geochemical processes in a semi-arid losing stream using temperature, isotopes and geochemistry, paper presented at 11th Australasian Environmental Isotope Conference & 4th Australasian Hydrogeology Research Conference, Cairns, Australia, 12-14 Jul 2011.**
- **McCallum, A. M., M. S. Andersen, G. C. Rau, and R. I. Acworth (2011), Using Combined Temperature, Flow and Level Data to Investigate River-Aquifer Interaction Scaling Issue, paper presented at AGU Fall Meeting 2011, San Francisco, USA, 5-9 Dec 2011.**
- **Rau, G. C., M. S. Andersen, and R. I. Acworth (2011), Is thermal dispersivity significant for the use of heat as a tracer in sediments?, paper presented at AGU Fall Meeting 2011, San Francisco, USA, 5-9th Dec 2011.**
- Andersen M.S. (2011): Surface Water Groundwater Interactions lecture given at Getting to Know Groundwater and Surface water Course run by the NCGRT 29th Sydney, March 2011.
- Andersen M.S., Acworth, R.I., Rau, G.C. & McCallum, A.M. (2010): Investigations of surface water ground-water interactions in a water stressed semi-arid catchment. Presentation at the Namoi Groundwater Forum organised by The Namoi Catchment Management Authority and the Cotton Catchment Communities CRC, Tamworth, NSW, 3rd of December 2010. Invited talk
- Andersen M.S., Rau G., McCallum A.M., Acworth R.I. (2010): On the temporal variability of streambed hydraulic conductivity investigated using heat as a tracer. Abstract and oral presentation at the Groundwater 2010 Conference, Canberra, Australia, 1-4 November 2010.
- Andersen M.S., Rau G., McCallum A.M., Acworth R.I. (2010): Investigations of surface water groundwater interactions in a water stressed semi-arid catchment. Oral presentation at the Geocenter, University of Copenhagen, Denmark, 24th September 2010.
- Rau G., Andersen M.S, Acworth R.I. (2010): Laboratory and field investigation of heat transport in shallow saturated hydrogeological systems. Oral presentation at the Umweltforschungszentrum, Leipzig, Germany, 21st September 2010.
- Rau G., Andersen M.S., Acworth R.I. (2010): Uncertainty of vertical streambed seepage rates under realistic field conditions using diel temperature fluctuations. Paper and oral presentation at the IAH Congress Krakow, Poland, 12-17 September 2010.
- Acworth R.I., Rau G., Andersen M.S. (2010): Use of natural heat as a tracer
- to quantify water flow in shallow saturated unconsolidated hydrogeological systems. NPSI Partners Forum, Sydney 27th July 2010.
- Rau G., Andersen M.S, Acworth R.I. (2010): Analytical methods that use natural heat as a tracer to quantify surface water-groundwater exchange, evaluated using field temperature records. Oral presentation at USGS Boulder, Colorado, Unites States, 23rd July 2010.
- Rau G., Andersen M.S, Acworth R.I. (2010): Analytical methods that use natural heat as a tracer to quantify surface water-groundwater exchange, evaluated using field temperature records. Oral presentation at USGS Salt Lake City, Unites States, 21st July 2010.
- Rau G., Andersen M.S, Acworth R.I. (2010): Analytical methods that use natural heat as a tracer to quantify surface water-groundwater exchange, evaluated using field temperature records. Oral presentation at USGS Reno, Unites States, 19th July 2010.
- Rau G., Andersen M.S, Acworth R.I. (2010): Analytical methods that use natural heat as a tracer to quantify surface water-groundwater exchange, evaluated using field temperature records. Oral presentation at USGS, Menlo Park, Unites States, 15th July 2010.
- Rau G., Andersen M.S, Acworth R.I. (2010): Analytical methods that use natural heat as a tracer to quantify surface water-groundwater exchange, evaluated using field temperature records. Oral presentation at IAH-NSW Monthly Meeting, PB Sydney, 9th February 2010.
- Rau G., Andersen M.S, Acworth R.I. (2009): The Use of Natural Heat as a Tracer to Quantify Groundwater Surface Water Interactions, Maules Creek, New South Wales, Australia. Oral presentation at the Maules Creek Groundwater Forum, Maules Creek, 20th November, 2009.
- Rau G., Andersen M.S., McCallum A.M., Acworth R.I. (2009): Field investigation using natural heat as a tracer to quantify surface water groundwater connectivity in Maules



Creek, NSW, Australia. Paper and oral presentation at the Joint IAH/IAHS International Convention, Hyderabad, India, 7-12 September 2009.

- Rau G., Andersen M.S, Acworth R.I. (2009): The Use of Natural Heat as a Tracer to Quantify Groundwater Surface Water Interactions, Maules Creek, NSW, Australia. Abstract and oral presentation at the Cotton CRC Science Forum Narrabri, 17-19 August, 2009.

Posters:

- Annual Cotton Science Forum, Narrabri, NSW, 26th to 27th October 2010: A Tool for Measuring Water Exchange Using Heat as a Tracer.
- The Irrigation Australia/Irrigation Futures CRC Conference, Sydney, June 2010: A Tool for Measuring Water Exchange Using Heat as a Tracer.
- NWC Groundwater Forum, Canberra, 24-25th November 2009: Design of an Advanced Hydraulics experiment to Simulate Heat and Solute Transport in Homogeneous and Heterogeneous Saturated Sediment
- Maules Creek Groundwater Forum, Maules Creek Hall, NSW, 20th November 2009: Field and Numerical Investigation of Surface Water Groundwater Interactions Using Natural Heat as a Tracer – Deviation from the 1D Flow Assumption
- Western Pacific AGU meeting, Cairns 28th of July – 1st of August 2008: Field and Numerical Investigation of Surface Water Groundwater Interactions Using Natural Heat as a Tracer – Deviation from the 1D Flow Assumption

Summary of participant's feedback from the various national and international promotional activities

Very positive feedback was received from researchers, groundwater managers, decision makers and farmers who have been participating in any of the promotional activities (see also the attached Project Log Frame). The total feedback received from workshops, meetings, presentations and national as well as international conferences can be summarised and compiled to a set of conclusions as follows:

- *Knowledge from heat as a quantitative tracer in Australia has mainly been driven by the current project.*
- *Heat as a tracer has received an ever increasing attention from the national and international research community.*
- *The international research community views the outcome of this research project as being of high quality, novel and unique.*
- *The national research community have increasingly recognised the potential of heat tracing research and new activities are in the planning.*
- *The national community involved in water management has heard about the possibilities of using heat as a tracer for the first time, and demonstrated interest in the practical applicability.*

On an international level, positive feedback regarding the quality of this research work was received from the international scientific community that are also engaged in heat tracing research. In particular: Prof. James Hunt (University of California), Christine Hatch (University of Massachusetts), Bethany Nielson (University of Utah), Martin Briggs (Syracuse University) Jan Fleckenstein (UFZ Hydrogeology Leipzig), Adam Ward (Pennsylvania State University), Stefan Krause (University of Birmingham), Jim Constantz, Ken Bencala and Judson Harvey (at the USGS).

12. Planned Knowledge, adoption and promotional activities and associated Evaluation activities

Workshop activity

No further workshop activities are planned within the context of current project. An international 2-day workshop on heat as a tracer will be held either the end of 2012 at WRL or as part of the international IAH conference which is planned for Perth 2013.

Delivery tactics for the final project products

The final project products, understood as being the temperature tool and associated Matlab scripts for data processing and interpretation, will be described and made public in international peer-reviewed journals and the scripts will be made freely available on our website. More generally the project outcomes and methodologies developed during the project will continue to be incorporated into course material for undergraduate and graduate university students at UNSW as well as into short courses for Australian water sector professionals under the NCGRT banner. This will ensure that the method will be continuously exposed to an increasing number of water professionals over the long term.



13. IP Register

IP issues relating to the project have been scoped by TechMAC Pty Ltd (Dallas Gibbs – to be forwarded by request). The overall assessment is that the scope for patenting and copyrights are limited since the methodologies derived in the project builds on pre-existing methodologies and technologies, this is particularly so for the hardware (the temperature tool). Furthermore it is the view of the project group that any software developed should be available as open source. With regards to the Magic Box it should be mentioned that it is a highly specialised piece of research equipment tailored for answering very specific research questions. It is unlikely that any other research group would need something similar, but in the event, they would probably build equipment for their own particular specifications.