# High resolution seismic survey of the proposed Beenyup wastewater injection site

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## SUMMARY

The Beenyup wastewater treatment plant is situated in close proximity to residential properties approximately 20 km north of the central business district of Perth, Western Australia. It is proposed that treated wastewater from the plant will be injected into the sub-surface in preference to releasing it to the ocean. In order for this to occur over a long period of time a good understanding of the connectivity of the sub-surface aquifers in the vicinity of the injection site is required.

High resolution surface seismic together with vertical seismic profiling data were collected at the site using a high-power impact source. The resulting sub-surface images correlate well with geophysical well-logs and clearly show the injection zone and confining seals.

**Key words:** Wastewater, Injection, Beenyup, Hydrology, high resolution seismic.

## INTRODUCTION

The Perth basin area of Western Australia has large reserves of groundwater that have been used for many years to supplement the water obtained from reservoirs. Like much of the Australian continent, Perth's water resources are under increasing stress from an increasing population coupled with decreasing rainfall. Extraction of groundwater for domestic and commercial use has occurred for many years to supplement the water collected in dams. For the last thirty years or so, groundwater has provided about 40% of Perth's water supply. The Superficial aquifer appears to be in a equilibrium state but the Leederville aquifer is in a depleted state as the rate of recharge is generally less than the extraction rate (Davidson, 1995). The effects of depleted groundwater on the natural environment may be severe and still need to be quantified. A potential for mitigating such potential stresses can be found in recycling highly treated wastewater. Modern wastewater treatment plants are able to produce large quantities of potable quality water (Li et al, 2006) that can be added to the water supply system. The technology required to produce large volumes of potable water is available but the problem has now become one of storage. What do we do with all this water when the demand decreases? Injecting the treated water back into the groundwater aquifers is a sensible and cost effective storage option that will help recharge the depleted aquifer during periods of lower water use in readiness for extraction when the demand increases. However, before embarking on such an option, containment of the injected water must be assured – especially in relation to possible 'escape' paths back to the surface.

The Centre for High Definition Geophysics (CHDG) at Curtin University in collaboration with the Western Australian Water Corporation has begun a geophysical study of the Beenyup site to help assess its suitability as a re-injection site, with particular emphasis on the continuity of the aquifer seals above the injection zone. It was decided that high resolution seismic survey is most likely to provide sufficient resolution to map changes in the layering at the depths of interest.

A simplified model of the main geological units based on drill samples taken at the Beenyup site is shown in Figure 1. The main injection zone is expected to be within the permeable sands/sandstones of the Wanneroo member of the Leederville formation between about 120 m and 220 m depth. The Pinjar member above the injection zone is expected to confine the injected water within the Wanneroo sandstone and prevent upward leakage.

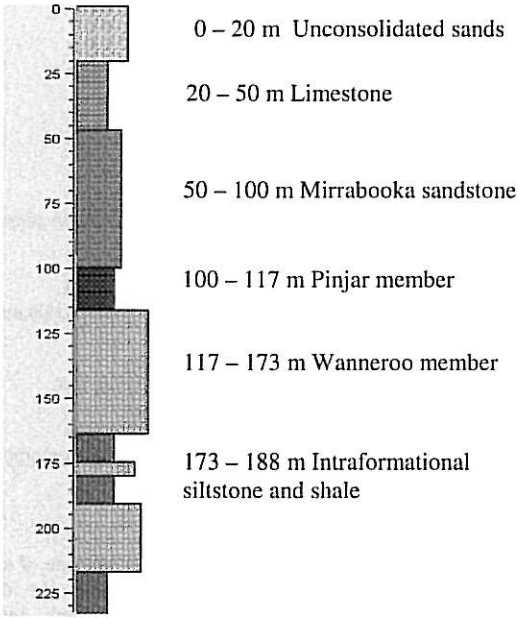


**Figure 1. Simplified geological model of the Beenyup injection site based on drill samples. The injection zone is expected to be between 120 m and 220 m depth.**

## 2-D SEISMIC SURVEY

The injection site at Beenyup is located in close proximity to Perth's main north-south freeway and railway line. Transient noise created by the traffic was expected to be problematic for the seismic instruments so the site was initially surveyed as a 2-D line to assist the planning of a 3-D survey later in 2007. The main objective of the 2-D survey was to verify that the various layers of interest could be resolved before carrying out a large 3-D survey. A west-to-east transect of approximately 400 m in length was surveyed using a high powered impact source that was stacked ten times at each shot location. The eastern end of the fixed-spread line was about 50 m from the freeway and railway line. Small receiver and shot intervals (2 m) were used to increase the common depth point (CDP) fold and signal to noise ratio. Data were recorded with a sample interval of 0.25 ms using CHDG's seistronics system.

The seismic data were processed at Curtin University using ProMAX software. Figure 2 shows a portion of the seismic section produced after residual statics were applied. The section displays a number of significant reflections. The superficial layer has a thickness of about 20 m below which is a region of inhomogeneous limestone showing a reflective boundary at about 35 m. The base of the limestone is known to be at about 53 m at the bore and can be seen in the section as a weak and disjointed reflector. There is a strong reflector at about 65 m depth and another weak reflector at about 75 m that corresponds with a large increase in the gamma count rate. However, the purpose of this survey was to resolve the Pinjar and Wanneroo members. Reflections near 100 m and 120 m correspond well with the top and base of the Pinjar member and a reflection at 180m corresponds with the top of the "intraformational" siltstone. There is a very weak response at about 200 m that corresponds with the base of the "intraformational" siltstone and shale. These reflections also correlate with an increased gamma count indicating that the layers are well resolved and the 3-D survey is likely to be successful.

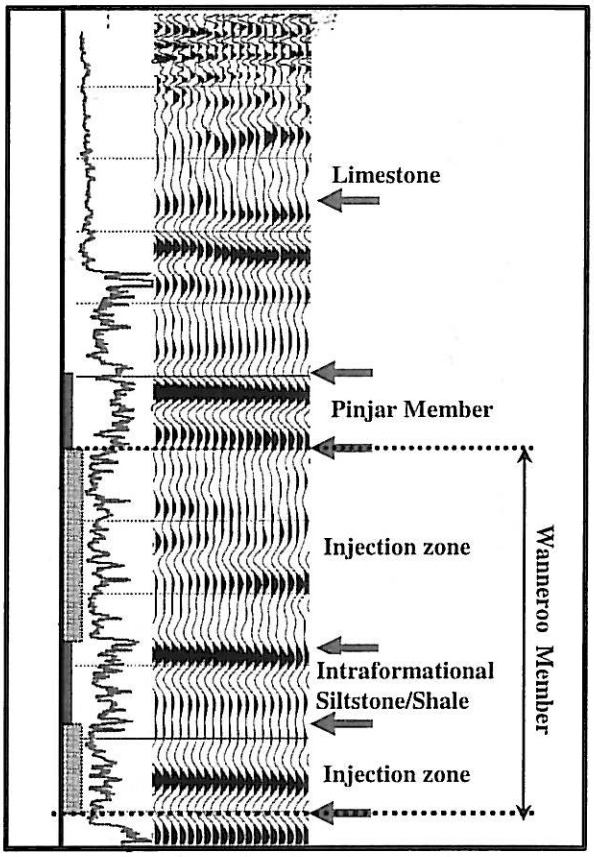


**Figure 2. Portion of the 2-D seismic test section showing the reflectors of interest. The seismic correlates well with the gamma log.**

## VERTICAL SEISMIC PROFILE

The Beenyup site has been equipped with a geophone string that is cemented into a bore located approximately 40 m from the proposed injection bore. The cemented geophone string will be used to monitor the changes in seismic velocity in the region of the injection zone to monitor any changes causes by the injection process. The sixteen geophones are located between 74 m and 284 m below the surface and spaced at 10 m intervals within the injection zone. A zero-offset vertical seismic profile (ZVSP) test was performed to test the string and establish a baseline for future comparisons.

Figure 3 shows the ZVSP stack obtained for the reflected waves. There are clear reflections at about 100 m and 120 m again indicating the top and bottom of the Pinjar member and clear reflections at about 180 m and 190 m corresponding with the intraformation siltstone and shale. Again, there is a very weak response near 200 m that is probably an indication of the base of the intraformational sandstone and shale. Further processing attempts will be made to improve the resolution below 200 m depth.

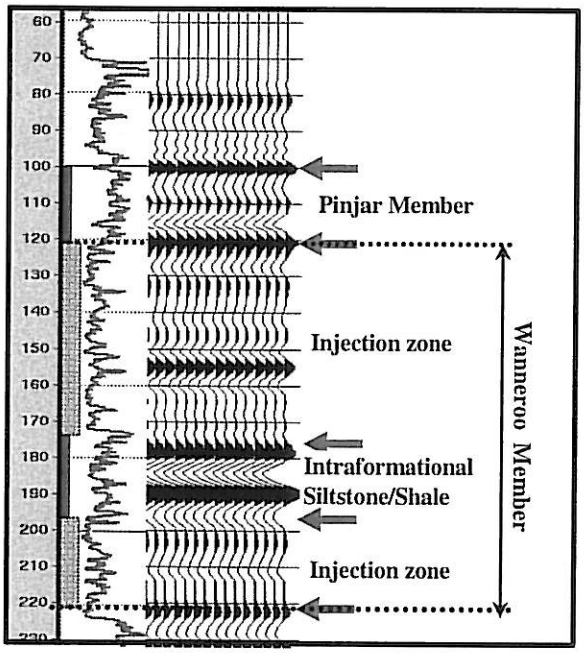


**Figure 3. Zero offset VSP stack showing the Pinjar and Intraformational siltstone and shale .**

## CONCLUSIONS

High resolution seismic survey of the Beenyup injection site has been shown to successfully resolve key hydrostratigraphic layers for the Beenyup Trial purified waste water injection project. The top and base of the Pinjar member (mostly clay/shale) above the injection zone are well resolved in both the 2-D and VSP data. This leads to expectation that the main 3-D survey will provide a detailed representation of the important hydrostratigraphic units at Beenyup.

## REFERENCES

Davidson, W.A., 1995, Hydorgeology and groundwater resources of the Perth region, Western Australia: Bulletin 142, Geological Survey of Western Australia.

Li, Q., Harris, B., Aydogan, C., Ang, M., and Tade, M., 2006, Feasibilty of recharging reclaimed wastewater to the coastal aquifers of Perth, Western Australia: Process Safety and Environmental Protection, 84 (B4), 1-10.

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|---|---|---|---|---|---|---|
| 15:30 | **Helicopter Trial of Magnetic Tensor Gradiometer**<br>Phillip Schmidt (CSIRO Exploration & Mining, NSW) | **Geological Interpretation of Potential Field Inverse Models Using Automated Classification**<br>Michael Roach (The University of Tasmania) | **Utilising the Two-Way Wave Equation: Reverse Time Pre-Stack Depth Migration**<br>Andrew Long (Petroleum Geo-Services, WA) | **Subcritical Crack Growth in Rocks Under Aqueous Environments**<br>Yoshitaka Nara (Hokkaido University, JAPAN) | **4D Pressure Pilot to Steer Well Spacing in Tight Gas**<br>Edwin Quint (Shell Development (Australia) Proprietary Limited, WA) | **Shallow Geophysical and Hyrogeological Studies to Characterise Palaeochannel Properties, A Case Study From Tanami Desert, NT**<br>John Joseph (University of Adelaide, SA) |
| 16:00 | **Instrument Forum** | **A Rapid Algorithm for Self-Potential Data Inversion with Application to Mineral Exploration**<br>Salah Mehanee (Macquarie University, NSW) | **A Wave Propagation Based Method for Improved Seismic Fracture Prediction**<br>Mu Luo (JGI Inc, JAPAN) | **Elastic Properties of Shales With Respect to Silt Fraction**<br>Marina Pervukhina (CSIRO Petroleum, ARRC, WA) | **Shale Gas Rock Properties Prediction Using Artificial Neural Network Technique and Multi Regression Analysis, an Example From a North American Shale Gas Reservoir**<br>Reza Rezaee (Curtin University of Technology, WA) | **High-Resolution Airborne Electromagnetic Surveying for Dryland Salinity Management: The Toolibin Lake SkyTEM Case Study, WA**<br>James Reid (Geoforce Pty Ltd, WA) |
| 16:30 | **Instrument Forum** | | **NIP Tomography Inversion: A New Improved Method for Velocity Model Estimation – A Synthetic Data Example**<br>Mehrdad Soleimani-Monfared (Shahrood University of Technology, IRAN) | **Laboratory Measurements of Stress-Induced Velocity Anisotropy in Unconsolidated Sands**<br>Don Sherlock (CSIRO Petroleum, WA) | **Operational Considerations for Optimising Pressure Test Results Using LWD Formation Tester**<br>Vanessa Lim (Woodside Energy Ltd, WA) | |
| 17:00 | | | **Investigation of Overburden Heterogeneity Effects and Their Removal Through High Resolution Tomography and Pre-stack Depth Migration**<br>Mamoru Takanashi (Japan Oil Gas and Metals National Corporation, JAPAN) | | **Production Optimisation in Horizontal Wells by three-Phase Flow Quantification: Case Studies from Malaysia**<br>Jack Harfoushian (Schlumberger, WA) | |
| 17:30 | CLOSE OF SESSIONS | | | | | |
| 18:00 | HAPPY HOUR IN THE EXHIBITION – *Sponsored by Hess* | | | | | Pavilions 1 and 2 – Level 1 |
| 19:00 | CONFERENCE DINNER – *Sponsored by Shell Development (Australia) Proprietary Limited* | | | | | Ballroom – Level 3 |



## WEDNESDAY 21 NOVEMBER 2007: DAY THREE

| | | | | | | |
|---|---|---|---|---|---|---|
| 07:15 | Chair and Speaker Breakfast | | | | | Ballroom Foyer – Level 3 |
| 08:00 | Registration | | | | | Central Foyer – Level 2 |
| | MINERALS 1.8 | MINERALS 2.5 | PETROLEUM 1.8 | PETROLEUM 2.5 | NEAR SURFACE 8 | GENERAL INTEREST 1 |
| Theme | Crustal/Regional | EM | Time Lapse | Seismic Acquisition Forum | Environmental/Engineering | Hyperspectral |
| | Minerals 1.8 Session – *Sponsored by Geoscience Australia* | | | Seismic Acquisition Forum – *Sponsored by Chevron Australia Pty Ltd* | | |
| Venue: | Meeting Room 7 – Level 2 | Meeting Room 8 – Level 2 | Woodside Theatre (Meeting Room 2) – Level 2 | Meeting Room 1 – Level 2 | Meeting Room 3 – Level 2 | Meeting Room 10 – Level 2 |
| Chair: | Ned Stolz, Gold Fields | Lisa Vella, TeckCominco | Andre Gerhardt, Woodside Energy | Murray Richardson, Geoscience Australia | Greg Turner, Geoforce | Paul Mutton, Southern Geoscience Consultants |
| 08:30 | **Opening up New Areas for Exploration in Queensland**<br>Kate Wilkinson (Geological Survey of Queensland) | | | **Seismic Acquisition** | **SEG DISTINGUISHED LECTURE**<br>**Some stupid seismic experiments I have done**<br>Don Steeples (University of Kansas, USA) (1 hour) | **Case Study: Combining Hyperspectral Imaging With Airborne Geophysics for Mineral Exploration**<br>Carina Simmat (Geoforce, WA) |
| 09:00 | **3D Geological Mapping and Potential Field Modelling of West Arnhem Land, Northern Territory**<br>Richard Lane (Geoscience Australia, ACT) | **Application of a New TEM Data Acquisition System Based on a HTS SQUIDMagnetometer (SQUITEM) toMetal Exploration in Broken Hill Area**<br>Eiichi Arai (Japan Oil, Gas & Metals National Corporation, JAPAN) | **Geophysical Imaging for $CO_2$ Monitoring of OBPP**<br>Kevin Dodds (CO2CRC/CSIRO Petroleum, WA)<br>Presented by Milovan Urosevic | **Seismic Acquisition** | | **Mapping Regional Alteration Patterns Using Hyperspectral Drillcore Scanner**<br>Alan Mauger (Primary Industries & Resources, SA) |
| 09:30 | **The Benefits of Wide Line Spaced Airborne Gravity Gradiometry on Regional Surveys**<br>Karel Zuidweg (Bell Geospace Limited, UK)<br>Presented by Colm Murphy | **Total Field EM for Highly Conductive Targets**<br>Andrew Duncan (Electromagnetic Imaging Technology Pty Ltd, WA) | **Fundamental Seismic Parameters of Injected $CO_2$**<br>Nasser Keshavarz Faraj Khan (Curtin University of Technology, WA), presented by Brian Evans | **Seismic Acquisition** | **Is it Time to Re-Engineer: Near-Surface Seismic Refraction Methods?**<br>Derecke Palmer (The University of New South Wales) | **Towards Coal Quality Estimation from Geophysical Logs**<br>Binzhong Zhou (CSIRO Exploration & Mining, Qld) |
| 10:00 | Morning Tea Break | | | | | Pavilions 1 and 2 – Level 1 |
| | MINERALS 1.9 | MINERALS 2.6 | PETROLEUM 1.9 | PETROLEUM 2.6 | NEAR SURFACE 9 | GENERAL INTEREST 2 |
| Theme | Crustal/Regional | Electrical | Time Lapse | Seismic Acquisition Forum | Environmental/Engineering | Potential Fields/Seismic |
| Venue: | Meeting Room 7 – Level 2 | Meeting Room 8 – Level 2 | Woodside Theatre (Meeting Room 2) – Level 2 | Seismic Acquisition Forum – *Sponsored by Chevron Australia Pty Ltd*<br>Meeting Room 1 – Level 2 | Meeting Room 3 – Level 2 | Meeting Room 10 – Level 2 |
| Chair: | Roger Clifton, Northern Territory Geological Survey | Michael Asten, Flagstaff GeoConsultants | Andre Gerhardt, Woodside Energy | Murray Richardson, Geoscience Australia | Gary Humphries, Department of Water, WA | Peter Milligan, Geoscience Australia |
| 10:30 | **Sub-Basalt Imaging from Gravity Studies over the Deccan Volcanic Province of Central India**<br>Bijendra Singh (National Geophysical Research Institute, INDIA) | **Looking Inside Pores: Polarisation by Constrictivity of Pores**<br>Valeriya Halibauer-Zadorozhnaya (Council for Geoscience, SOUTH AFRICA) | **Using 4D Seismic Data to Understand Production-Related Changes in Enfield, NWS Australia**<br>Megan Smith (Woodside Energy Ltd, WA) | **Seismic Acquisition** | **3D Seismic Reflection Survey Design and Modelling at the Beenyup Waste Water Treatment Site, Western Australia**<br>Chris Semeniuk (Curtin University of Technology, WA) | **Influence of Self-Demagnetisation Effect on Data Interpretation in Strongly Magnetic Environments**<br>Richard Krahenbuhl (Colorado School of Mines, USA) |
| 11:00 | **Potential Field "Worms" and Models as the basis of a 3DTectonic Model of the Koonenberry Belt, North-Western NSW**<br>Bob Musgrave (Geological Survey of NSW) | **Six Years Experience with Offset Pole–Dipole and other 3D IP Arrays**<br>Steve Collins (Arctan Services Pty Ltd, NSW) | **The Role of Rock Physics Modelling for the Enfield 4D Seismic**<br>Angelika Wulff (Woodside Energy Ltd, WA) | **Seismic Acquisition** | **High Resolution Seismic Survey of the Proposed Beenyup Wastewater Injection Site**<br>Michael Sykes (Curtin University of Technology, WA) | **Automatic Analysis of Aeromagnetic Images for Gold Exploration**<br>Eun-Jung Holden (University of Western Australia) |

# Preview

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**Sent:** Tuesday, 17 July 2007 4:14 PM
**To:** [redacted]
**Subject:** ASEG Conference - your paper acceptance
**Attachments:** ASEG 2007 ExtendedAbstract.doc; Audiovisual Form.doc

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**RE: 19th International Geophysical Conference and Exhibition 2007**
***hosted by ASEG / PESA / FESWA***

On behalf of the organising committee, I am pleased to advise that your abstract entitled: *Non-Linear Joint AVO Inversion of PP and PS Waves in a VTI Medium* has been accepted for **oral** presentation at the conference.

To assist us, please confirm receipt of this letter and your participation in the conference by **Friday 27 July 2007**. A reminder that accepted authors are expected to complete registration and payment procedures prior to the close of the early bird registration deadline (Friday 21 September 2007).

The program format is in preparation and you will be advised in due course of the day and time of your presentation. Oral presentations will be allotted a maximum of 20 minutes plus 5 minutes for discussion.

As advised in the Call for Abstracts, accepted authors are required to submit a short paper / extended abstract for inclusion on the conference CD. Papers will be reviewed for technical content and undergo editorial review.

The guidelines for short papers / extended abstracts is attached. The **deadline for paper submission is Friday 21 September 2007.** Papers that do not meet the guidelines will not be published on the CD. Please note: the editor's decision will be final.

All abstracts accepted for the conference including posters, will be published in the conference program/proceedings. Should you wish to submit a revised abstract, the **deadline for revised abstracts is Friday 31 August 2007.**

Audiovisual requirements must be advised by **Friday 21 September 2007** and a form is attached for completion. Please note, that powerpoint is the preferred mode of presentation, projected to a single screen.

We will be in further contact as planning progresses. However, if at any stage you become unable to present at the conference, please inform us immediately, to allow us the opportunity to offer an oral presentation to another author and to maintain the integrity of

the program.

We thank you for your contribution.

Michelle Ainsworth (Mrs)
Conference Coordinator
Promaco Conventions Pty Ltd

17 July 2007

<<...>> <<...>>

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## References

References should follow the author (date) system. When reference is made in the text to a work by three or more authors, the first name followed by *et al.* should be used on all occasions. References should be listed in alphabetical order at the end of the paper in the standard form:
Blackburn, G. J., 1981, Seismic static corrections in irregular or steeply dipping water-bottom environments: Exploration Geophysics, 12, 93-100.

## Abbreviations and units

SI units are preferred. Statistics and measurements should always be given in figures e.g. 10 mm, except where the number begins a sentence. When the number does not refer to a unit of measurement, it is spelt out, except where the number is greater than nine. Confusing mathematical notation, and particularly subscripts and superscripts, should be avoided; negative exponents or the use of a solidus (i.e. a sloping line separating bracketed numerator and denominator) are acceptable as long as they are used consistently. The words 'Figure' and 'Table' should be capitalised (first letter) and spelt in full, when referred to in the text.

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