

5th Western Australian State

# COASTAL CONFERENCE 2009

*Whose Coast Is It?  
adapting for the future*

## The Lighter Side of Turbidity: A Case Study

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### Introduction

The management of marine and coastal infrastructure construction is critically important in order to ensure development takes place in a sustainable and environmentally responsible manner. The impact of turbidity and light attenuation associated with construction within the marine environment on Benthic Primary Producer Habitat (BPPH) is widely adopted as a key indicator of the impact of marine construction on the wider aquatic ecosystem. A well founded and responsive management strategy is the keystone that ensures the economic, environmental and social amenity of the site and surrounds is maintained during and after construction.

In accordance with the management plan for the Alkimos Wastewater Treatment Scheme Pipeline Construction (Worley Parsons, 2008) Cardno was appointed to develop and implement an extensive water quality and benthic habitat monitoring programme. Monitoring for the first phase of construction commenced in November 2008 and was completed in June 2009. During this phase the pipeline route was largely established by blasting and dredging a pipeline trench between the coastline and 3.7km offshore.

This paper provides an overview of the water quality monitoring programme that was undertaken (Cardno Lawson Treloar, 2009). Significant turbidity time series analysis was conducted to identify periods of time where elevated turbidity was the result of construction or ambient forcing. Through extensive field investigations a strong, statistically significant correlation between turbidity and light attenuation is established for the construction site. On this basis an assessment of the overall impact on irradiance at the seabed due to construction turbidity across the construction site was made with good agreement with the results of the benthic primary producer monitoring programme (Cardno Ecology Lab, 2009).

9A:  
Marine  
Monitoring:  
10.55–11.25am  
Friday 9th  
October 2009  
Orion Room

# Background

## Study Site

Alkimos is located approximately 45 km north of Perth. The region is named for the ship wreck that lies approximately 1 km north of the outfall pipeline alignment. The shoreline is characterised by large undulating dunes. Alkimos beach is a predominantly reflective sandy beach extending north from Mindarie to Two Rocks with some sections perched on coastal limestone. Offshore, large segments of vegetated limestone reefs are present with the area being a popular commercial and recreational fishing and diving location. The location is exposed to long period ocean swell and locally generated seas.

## Turbidity Generation and Measurement

The presence of suspended and dissolved sediment and organic matter in water result in light being attenuated as it passes through the water column. Turbidity is used as a proxy measurement of such suspended and dissolved sediment, and organic matter. Turbidity sensors operate by means of measuring optical backscatter; a light is emitted into the water and the intensity of scattered light reflected at 90 degrees is measured.

A variety of physical processes can result in the suspension of particles present on the seabed. The presence of currents and the passage of waves through shallow water result in large water velocities and associated shear at the seabed. If the shear is sufficient to overcome the variety of forces constraining the particles to the substratum, then suspension of sediments and organic matter will occur and turbidity will be generated. The threshold shear required for suspension is dependent on the complex interaction between a variety of particle and flow properties. In the coastal environment at Alkimos, the primary driver to observed turbidity is the suspension of sediments (inorganic and organic) from the seabed from wave forcing.

The distribution of particle sizes is important in determining the extent and persistence of generated turbidity. Large particles generally have a greater settling velocity and will therefore fall back to the sea bed rapidly once conditions causing suspension subside. Small and fine particles will tend to remain suspended in the water column for much longer periods of time.

Construction activities, such as dredging and blasting also result in the generation of turbidity due to the associated disturbance to the substratum and dispersion of sediments through the water column. In general, natural processes will result in turbidity generated at the seabed and dispersed through the water column, whilst construction activities generally generate turbidity at a single point but with a greater vertical extent. Measurement of turbidity is usually confined to point measurements, in which case the distance of the measurement point from the turbidity source has a large influence on the measured turbidity. The rate of sediment suspension during dredging, the type of sediment suspended and the ambient hydrodynamic conditions are major factors determining the extent and magnitude of generated turbidity plumes.

The heterogeneity of natural physical processes, for example the variability of wave height in space and time, in conjunction with the close proximity of the turbidity source (seabed below the instrument) result in measured turbidity that exhibits a large variance due to the measurement of a wide range of particle sizes. In contrast, construction activities generally occur some distance from the measurement point, with generated turbidity taking some time to advect to the sensor location. Given sufficient time large particles will tend to settle out of the water column, resulting in generally small and fine particles remaining in suspension and measured turbidity that exhibits significantly less variance.

## Methodology

### Monitoring Design

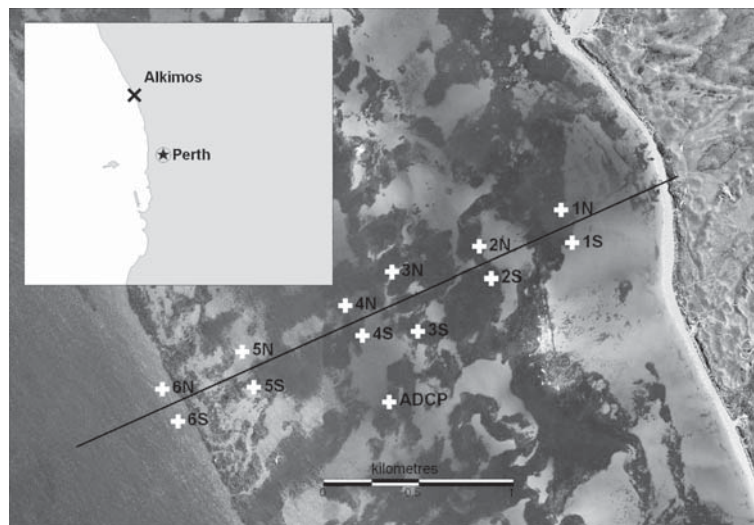
The turbidity monitoring design consisted of three main components:

- Fortnightly deployments of (six to eight) continuous logging turbidity sensors along the construction corridor;
- Collection of wave and current data from an ADCP instrument located close to the pipeline route; and
- Fortnightly water column profiles of turbidity, light and suspended sediments.

In addition a specific turbidity plume mapping exercise was undertaken on 26 March 2009 involving vertical water column profiles of light and turbidity 'upstream' and 'downstream' of the dredging activities as well as towed horizontal transects of light and turbidity at approximately 3m depth through the turbidity plume

present. Figure 1 provides a locality plan view of the turbidity monitoring sites and ADCP deployment location.

**Figure 1. Locality plan view of construction site with pipeline alignment and monitoring locations shown.**



### **Continuous Logging Turbidity Sensors**

Data-logging turbidity sensors were deployed at a total of three or four locations along the pipeline route at any one time. At each location sensors are deployed approximately 100m north and 100m south of the pipeline route. Each site was spaced approximately 500m along the pipeline corridor, with the first site located at chainage 500m (Figure 1). Depending on the current direction at any point in time, this instrument configuration provides continuous upstream and downstream turbidity measurements along the construction corridor. The transport of turbidity plumes will likely be dominated by advective transport rather than dispersive processes, therefore at any point in time the upstream sensor provides a measure of ambient turbidity.

McVan Analite NEP495 Turbidity/Temperature Logging Probes were utilised for continuous turbidity logging. Each probe is fitted with a mechanical wiper to wipe the sensor area clear of any fowling. The turbidity sensors are deployed approximately 0.4m above the seabed on simple rigs which involve star pickets driven into the seabed by a diver. The sensors are attached to a PVC pipe assemblage using duct tape and zip-tie devices. This assemblage is taken down by the diver, passed over the star picket and secured using additional zip tie devices. In general all logging instruments were deployed in the presence of a Cardno representative. Prior to each deployment the sensors were configured to a turbidity range of 1000 NTU. The instrument clocks were reset and the device configured to log every 2 minutes, performing a wipe of the sensor face prior to every measurement. The turbidity sensors were recovered every two weeks and taken ashore to download data and clean any fowling. At the earliest available time, the instruments were re-deployed at locations appropriate to the expected work area over the next two week period. Depending on weather and availability of boats and divers, the time between recovery and deployment could vary between one and seven days.

### **ADCP wave and current device**

In addition to the continual monitoring of turbidity, metocean conditions were recorded using an RDI 600kHz Acoustic Doppler Current Profiler (ADCP). The ADCP was mounted to a standard ADCP frame and lowered to the seabed using a slip-line configuration. Additionally a ground line was laid out from the instrument to assist in location and recovery of the instrument. The instrument was deployed in approximately 12m of water. The ADCP was configured for deployment with 48 vertical cells of 0.35m depth. The first cell started 1.41m above the seabed. Currents were measured every 10 minutes via ensembles comprised of 60 pings. These settings resulted in a maximum standard deviation of 3.13 cm/s. Waves were measured using 20 minute bursts each hour. The ADCP was deployed and retrieved at the same time as the continuous logging turbidity instruments. Data was copied from a memory card installed in the ADCP. The data was then post processed using WavesMon™ to extract current and wave information.

## Water column sampling of turbidity, light and suspended sediments

During the instrument recovery trips turbidity, light and suspended sediments samples were collected through the water column at each sensor location. Turbidity and light were measured using a Seabird SBE19 CTD equipped with a McVan Analite NEP395GP Turbidity probe used to measure turbidity and a Satlantic PAR (600m) sensor used to measure irradiance. Data was captured in real-time using a customised data-acquisition program developed by Cardno. The CTD was lowered at a constant rate from the side closest to the sun to ensure that the device did not pass through the shadow of the boat and accurate light profiles could be obtained. Post-processing of CTD output was performed to align data from the sensors in space and time using SBEDataProcessing-Win32.

Suspended sediment samples were collected for each site at three locations in the water column—upper, middle and lower. A one litre sample bottle was taped to a weighted rope marked at 1 m intervals. The top of the bottle was sealed using a rubber stopper attached to a string that was fed out as the bottle was lowered. Once the bottle was at the appropriate depth the rubber stopper was removed by a sharp tug upon the string, allowing the bottle to fill. The bottles were then sealed, labelled and sent for laboratory analysis. Laboratory analysis was performed by the Perth Environmental Division of the ALS Laboratory Group.

## Data Analysis

Time series of turbidity and metocean conditions (waves and currents) were prepared and examined in conjunction with construction activity logs to identify turbidity generated by construction activities. Construction turbidity impacts typically exhibited low variance compared to ambient forcing. Periods of time demonstrating construction impacts were logged.

For each 10 minute current sample and 20 minute wave burst the median turbidity was calculated and a least squares regression performed between turbidity and metocean conditions (wave height, wave period and current speed).

An estimate of the light attenuation coefficient (LAC) for each vertical cast was calculated by performing a linear least squares fit to the natural log transform of Equation 1. Ordinary least squares regression was then performed between the vertically averaged turbidity (NTU) and the estimated LAC. Vertical light profiles that exhibited a clearly unrealistic form (due to shadowing or waves) and low statistical reliability ( $R^2 < 0.5$  and  $p\text{-val} > 0.1$ ) were excluded from the correlation analysis between NTU and LAC.

$$I(z) = I_0 \exp(kz)$$

### Equation 1. Model describing the exponential decay of irradiance as a function of depth ( $z$ ) and an attenuation coefficient ( $k$ ).

For each horizontal transect the irradiance, depth and turbidity data were processed with a low-pass square windowed three second running mean filter. The attenuation coefficient at each point along the horizontal transects was estimated based on the depth,  $z$ , irradiance at depth,  $I(z)$ , and assuming that the incident light intensity,  $I_0$ , along the transect was equal to the mean  $I_0$  calculated in the fit of Equation 1 to each of the 'upstream' vertical profiles obtained on that day. On this basis a relationship between turbidity and light attenuation is established over a large turbidity range.

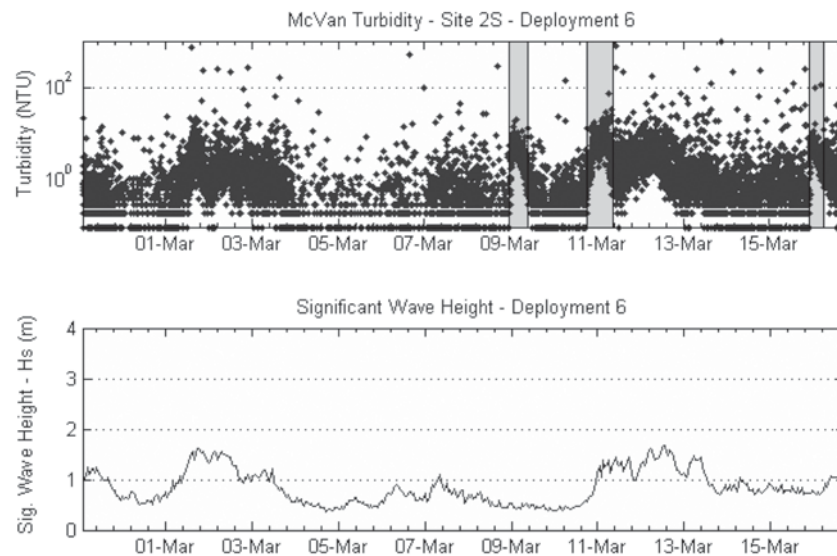
## Results

Figure 2 shows the time series of turbidity recorded at Site 2S during Deployment 6 and significant wave height recorded by the ADCP over the same period. Elevated turbidity forced by swell conditions are visible on 1st to 4th March and 11th to 14th March 2009. Elevated turbidity forced by construction activities are shaded. Based on the time series and identified construction impacts it is possible to plot the cumulative probability distributions for the ambient periods, construction impacted periods and the combined period to assess the overall impact construction activities had on turbidity levels at the site. An example for Site 2N is shown in Figure 3 for the construction period from November 2008 to June 2009. To quantify the increase in turbidity the integral of each cumulative probability distribution is calculated. An overall increase in turbidity due to construction of 13% was observed at Site 2N over the construction period.

Figure 4 provides an example of four vertical light and turbidity profiles obtained on 26 March 2009. Figure 5 shows a scatter plot of turbidity verses the light attenuation coefficient calculated for the vertical casts obtained on 26 March 2009. As expected, a systematic, statistically significant relationship exists between turbidity and light attenuation. Figure 5 provides a limited range of turbidity values over which to establish the relationship. Figure 6 presents a scatter plot of estimated light attenuation against turbidity at calculated at each point along the horizontal transects.

The estimate of light attenuation calculated along the horizontal transects is in good agreement with the values calculated by directly fitting the vertical light profiles in Figure 5. Figure 6 establishes the relationship over a larger range of turbidity values that are experienced during ambient and construction periods. An exponential relationship between light attenuation and turbidity provides a better fit than a linear relationship. Using the exponential fit it is possible to assess the impact on irradiance reaching the seabed over the entire construction period for ambient conditions and construction events by integrating Equation 2 over the probability distribution of turbidity measured at each site. A representative depth of 7m was chosen for the construction site over which to assess the reduction of light. Sites 4 through 6 were deployed for significantly less time than Sites 1 to 3 as dredging and blasting activities were concentrated in the proximity of Sites 1 to 3. The greatest impact on light penetration to 7m depth over a two-week deployment was 6.5% at Site 2N during February. Table 1 presents the overall reduction in irradiance at 7m depth at each site for the entire duration of construction (November 2008 to June 2009). The maximum reduction in light was estimated at 3.1% for Site 2N.

**Figure 2. Example time series of turbidity at Site 2S (top) and significant wave height (bottom) recorded for Deployment 6 (bottom).**



**Figure 3. Cumulative probability distribution at Site 2 for the entire construction period showing that turbidity levels were significantly elevated during identified construction impacts, however this resulted in a small overall increase in turbidity overall. Construction activities resulted in a cumulative increase in turbidity of 13% over ambient conditions.**

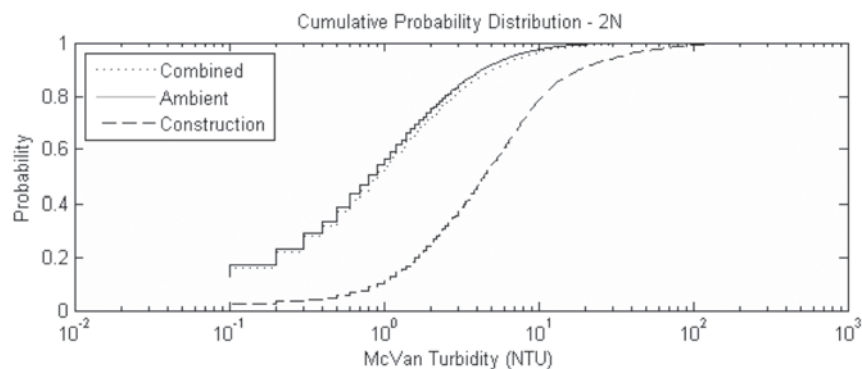


Figure 4. Example vertical profiles of turbidity and light from four casts obtained on 26 March 2009.

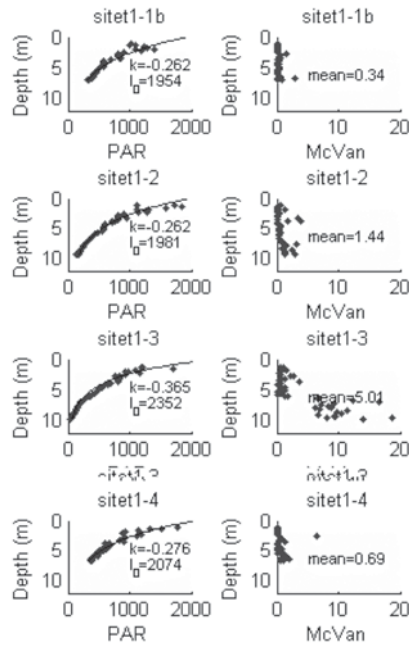
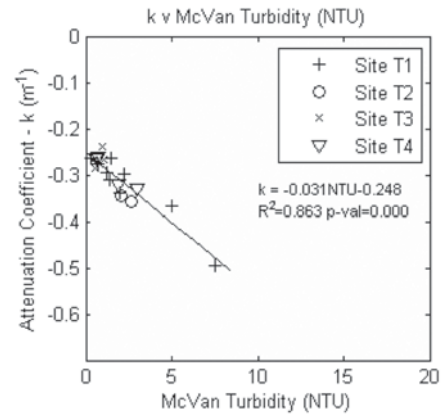


Figure 5. Relationship between turbidity and light attenuation based on the vertical casts obtained on 26 March 2009.



$$k = 0.459e^{-0.105NTU} - 0.678$$

Equation 2. Function describing the relationship between turbidity and light attenuation at the Alkimos Pipeline Construction site estimated from horizontal transects through the construction turbidity plume.

Figure 6. Scatter plot of turbidity versus attenuation coefficient estimated along the transects obtained on 26 March 2009

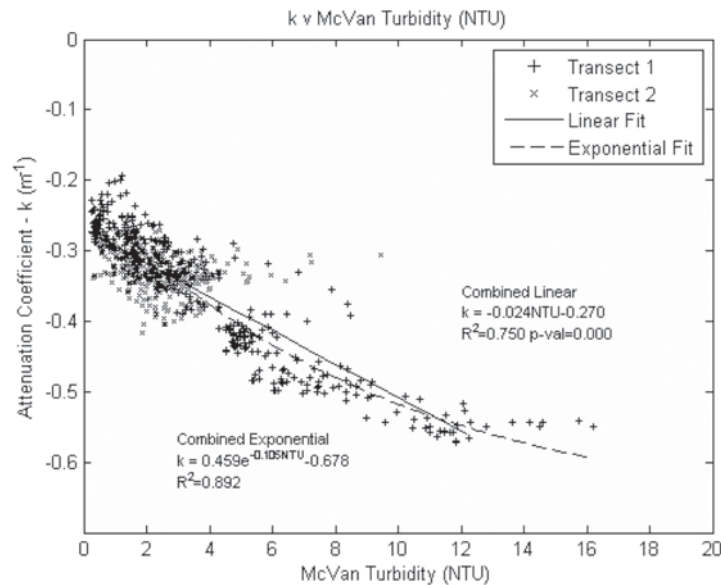


Table 1. Estimated overall reduction in irradiance at 7m depth due to construction activities for the entire construction project (November 2008 to June 2009). The maximum overall reduction in light was estimated at 3.1% for Site 2N.

Site	Overall Reduction (%)
1N	1.6
1S	2.2
2N	3.1
2S	0.7
3N	1.2
3S	0.6

Site	Overall Reduction (%)
4N	0.8
4S	2.6
5N	—
5S	—
6N	1.7
6S	—

## Benthic Habitat Monitoring

In conjunction with the water quality monitoring programme which is discussed here, monitoring of the Benthic Primary Producer Habitat (BPPH) also occurred between November 2008 and June 2009. The results from the BPPH monitoring were the primary indicator in the management plan of construction impacts on the aquatic environment. The overall outcome of the benthic monitoring program between November 2008 and June 2009 was that apart from direct habitat loss along the pipeline corridor there was no net impact on the surrounding seabed compared to reference sites.

Whilst no net impact was observed over the whole project, impacts were observed over the course of the benthic habitat monitoring programme. After the third survey in early February, the net impact on the BPPH was estimated at a loss of 4.3% which initiated a Level 1 management response (Cardno Ecology Lab, 2009). The primary cause of this result was the observed covering of BPPH with sand in the impact area of which covered habitat was assumed to have complete mortality. In the subsequent fourth survey in early March the net impact reduced to 1.2% due to the dispersion of the sand with very little mortality observed in the region that had been covered. The source of the sand which covered BPPH in Survey 3 is likely to have been the result of a combination of ambient conditions, blasting activities and dredging. These impacts were observed to be greatest approximately 1000m offshore. This is in good agreement with the results of the turbidity monitoring program where the greatest impacts were observed in February in the proximity of Site 2 (1000m offshore).

## Conclusion

An extensive water quality monitoring program was designed and implemented for the first phase of the Alkimos Wastewater Treatment Scheme Pipeline construction. Extensive analysis of turbidity time series was undertaken to identify construction impacts on ambient turbidity levels. The maximum impact observed over a two week deployment was 6.5% and over the entire construction period 3.1% at approximately 1000m offshore. This is in good agreement with observed BPPH monitoring. The use of the BPPH as the primary trigger for management response is inherently reactive due to the logistical delays associated with the measurement and analysis of BPPH assessment. The results presented here provide a foundation on which to establish proactive triggers based on water quality monitoring outcomes, resulting in a management plan with greater responsiveness. Table 2 outlines the proposed relationship between light reduction and BPPH impacts and triggers proposed for the water quality monitoring programme during the 2009–2010 pipeline construction period.

**Table 2—Recommended Impact Thresholds during the 2009–2010 pipeline construction period for Light penetration to the seabed over a 14-day monitoring period.**

Management Level	Impact on BPPH—% reduction	Net Reduction in Light Penetration @ 1m above the Seabed over a 14-day Monitoring Period
Within Defined (Allowed) Impacts	< 2%	< 3%
Level 1 Management Response	≥ 2% < 5%	≥ 3% < 7%
Level 2 Management Response	≥ 5%	≥ 7%

## References

- Cardno Ecology Lab (2009). Alkimos WasterWater Pipeline Benthic Habitat Routine Monitoring—Survey 6 (After 2008/2009 Construction Period). Prepared by Cardno Ecology Lab for the Alkimos Water Alliance. Ref: EL0809020 F.
- Cardno Lawson Treloar (2009). 'Alkimos Wastewater Treatment Scheme Pipeline Construction Water Quality Monitoring Summary Report'. Prepared for the Alkimos Joint Venture. 6 August 2009. LJ15001/Rep1004p-v2.
- WorleyParsons (2008). 'Alkimos Wastewater Treatment Scheme—Management Plan for Construction and Ongoing Presence of the Ocean Outlet Pipeline'. Prepared by WorleyParsons for the Alkimos Water Alliance, July 2008.