

Report prepared for Grange Resources limited  
by  
Optek Pty. Ltd.

In-Lab determinations of light attenuation versus TSS concentration for a  
variety of sediment cores samples.

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This study was conducted to determine the relationship between light attenuation and suspended sediment mass concentration of 4 core sediment samples.

### **INTRODUCTION:**

In all natural waters, downwelling light from the sun and the sky (Downwelling Irradiance –  $E_d$ ) is attenuated by particles and dissolved substances present in suspension, by the processes of scattering and absorption. The amount of incident downwelling light attenuated is proportional to the thickness of the natural water medium that the light passes through and the concentration of the particles within that medium.

This can be adequately described by the Beer-Lambert Law:

$$E_d(z, \lambda) = E_d(0, \lambda) e^{-K_d(z, \lambda)z} \quad (1)$$

Where  $E_d(z, \lambda)$  is the observed irradiance through a particular medium thickness,  $z$  (depth)

$E_d(0, \lambda)$  is the incident irradiance

$K_d(z, \lambda)$  is the attenuation coefficient

$z$  is the medium thickness (depth)

Downwelling Irradiance ( $E_d$ ) and the attenuation coefficient ( $K_d$ ) as used in the Beer-Lambert law usually refers to particular narrow-band (monochromatic) wavelengths of light, however for particular regions where sediment particles dominate light attenuation, PAR sensors have been used to determine the attenuation of PAR ( $K_d(\text{PAR})$ ) and its relationship with the suspended mass concentration of particles in the water column (TSS – Total Suspended Solid mass concentration) as measured in the field by sea water filtration and dry filter weight measurements.

$$K_d(\text{PAR}) \propto \text{TSS} \quad (2)$$

### **METHOD:**

A purpose-built calibration facility consisting of a 300 L sample volume, a voltage regulated fixed diffuse light source and a height-adjustable submerged light sensor was used to measure the decay of light in the sample volume for different types and concentrations of sediment (See Figure 1). All internal surfaces within the tank were coated in matt black paint to minimise light scattering. The light source consisted of a 50 Watt halogen lamp and a 3 mm PTFE disc covering the aperture to produce a diffuse light source. A 2 horsepower Davey water pump was used to circulate the water within the tank setup. The water pipe end was positioned 0.75 m above the light source which ensured there was enough water flow to remove any settling sediment which may cover the light source optical aperture. A black lid was placed over the tank cylinder to block out any external light from entering inside the tank.

The tank was filled with tap water, and the water pump and light source was turned on. A 10 minute warm up time was used to reduce the influence of air bubbles and to stabilize the light

source. The irradiance spectrum of the tap water medium (blank) was measured with a HOBI Labs, Hydrorad II planar irradiance sensor, for lamp-to-sensor distances of 84.0, 119.0, 159.0, 245.0, 344.0, 451.0 and 619.0 mm (all  $\pm 2$  mm). A “blank” water sample was taken by dipping a 5 L HDPE bottle in the centre of the tank cylinder.

The dry sediment from core VC06 was added to a bucket of water and mixed into a thick paste. A small amount of this paste was then added to the tap water and irradiance measurements, for the same lamp-to-sensor distances as for the blank, were acquired. After each addition of sediment, we waited 5 minutes to maintain optical homogeneity by rapidly cycling sediment through the system with the water pump. For each of the sediment concentration used, triplicate water samples were drawn from the centre of the chamber.

The above procedure was repeated for the remaining core samples (VC16, VC23, and VC55).

The water samples were stored overnight in 1 L HDPE bottles and then filtered under low vacuum pressure ( $<7.5$  inHg) onto pre-weighed  $0.5 \mu\text{m}$  nominal (47 mm Advantec GF/F GC 50). Filter funnels were rinsed with Milli-Q water during the final stages of each sample volume filtration. Filters were dried overnight at  $70^\circ$  Celsius before the initial and final weights to remove the weight of moisture deposited on the filters not attributable to the sample sediment concentration. The mass difference of each filter was divided by the volume of the sediment sample concentrated onto the filter to determine the mass concentration of sediment.

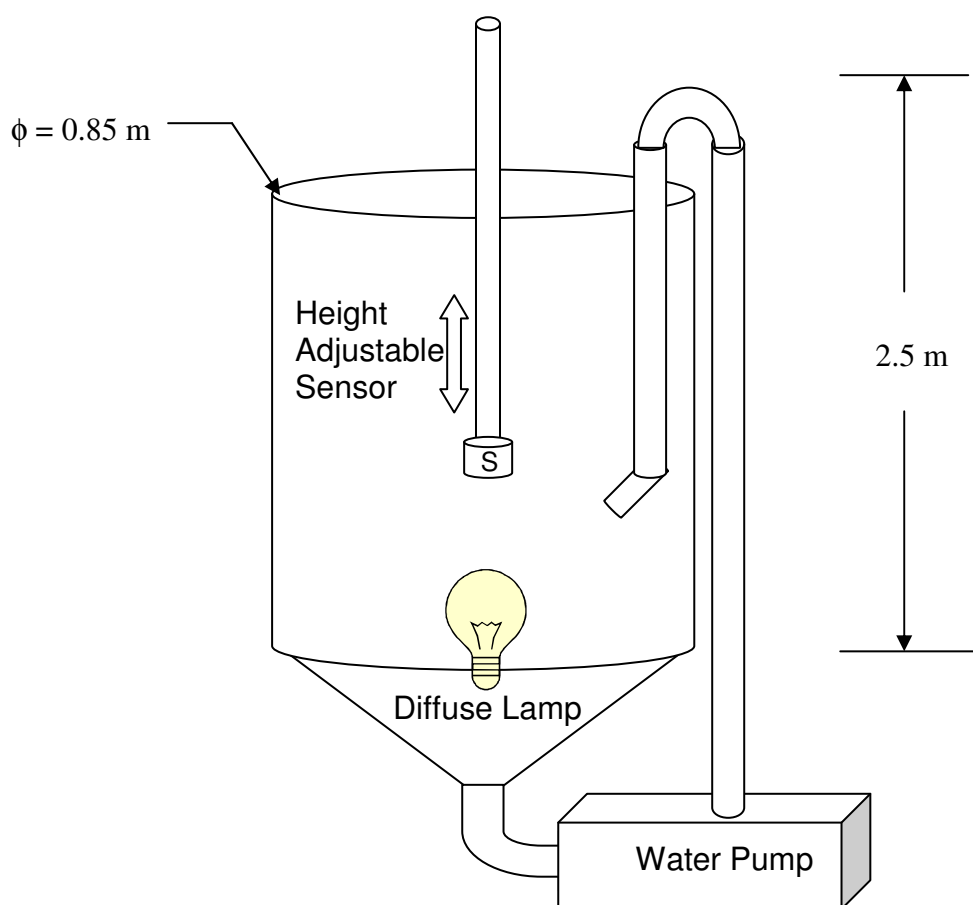


Figure 1 – Calibration chamber setup

## **DATA ANALYSIS:**

Hyperspectral Irradiance data was measured for the range of sensor – lamp distances ( $z$ ) described in the method. This data was converted to a PAR measurement by integrating the data over the PAR wavelength region (400 – 700 nm).

$$PAR(z) = \int_{700 \text{ nm}}^{400 \text{ nm}} E_d(z, \lambda) d\lambda \quad (3)$$

The PAR measurements were then normalised to the PAR measurement of tap water blank. This was required in order to correct the data for the combined effects of the  $1/R^2$  intensity drop-off and the unique light – sensor – tank geometry.

$$PAR(z) = PAR^{\text{Sediment}}(z) / PAR^{\text{TapWater}}(z) \quad (4)$$

The attenuation coefficient,  $K_d(\text{PAR})$ , for each sediment concentration and sediment type was calculated by rearranging Eqn. 1 as,

$$K_d(\text{PAR}) = -\frac{1}{z} \ln \left[ \frac{PAR(z)}{PAR(0)} \right], \quad (5)$$

where  $PAR(z)$  represents the tap water-normalised PAR at a distance  $z$  from the initial  $PAR(0)$  measurement. The mean and standard deviation of  $K_d(\text{PAR})$  for each sediment concentration and sediment type (see right column of the tables below) was determined from the calculations for the various lamp-sensor distances profiled within the tank. For high sediment concentrations the furthest lamp-sensor distances were omitted due to low signals recorded by the sensor.

The attenuation coefficient for each sediment concentration and sample was then regressed with the average blank-corrected total suspended solids value (left column in the tables below) determined from the water sample triplicate measurements.

## **RESULTS:**

The calculated  $K_d(\text{PAR})$  values corresponding to the various concentrations of TSS of the 4 sediment cores are tabulated below.

Core Sample: VC06	
TSS (mg/L)	$K_d(\text{PAR})$ (1/m)
$55.23 \pm 2.77$	$3.30 \pm 0.16$
$95.84 \pm 0.52$	$6.11 \pm 0.22$
$117.76 \pm 10.79$	$8.32 \pm 0.08$
$167.92 \pm 12.77$	$12.74 \pm 0.13$

Core Sample: VC16	
TSS (mg/L)	$K_d(\text{PAR})$ (1/m)
$4.06 \pm 0.48$	$0.29 \pm 0.08$
$11.14 \pm 1.45$	$0.73 \pm 0.09$
$22.28 \pm 2.76$	$1.13 \pm 0.03$
$53.10 \pm 7.33$	$2.40 \pm 0.05$
$127.05 \pm 13.45$	$4.59 \pm 0.30$

Core Sample: VC23	
TSS (mg/L)	$K_d(\text{PAR})$ (1/m)
$3.79 \pm 0.83$	$0.08 \pm 0.08$
$16.08 \pm 0.14$	$0.61 \pm 0.11$
$36.82 \pm 0.60$	$1.61 \pm 0.18$
$61.48 \pm 3.36$	$2.90 \pm 0.16$
$76.44 \pm 1.03$	$3.89 \pm 0.14$

Core Sample: VC55	
TSS (mg/L)	$K_d(\text{PAR})$ (1/m)
$8.911 \pm 0.72$	$0.42 \pm 0.04$
$76.11 \pm 18.68$	$2.05 \pm 0.07$
$145.86 \pm 20.80$	$3.28 \pm 0.18$
$212.65 \pm 24.76$	$5.29 \pm 0.63$

Figures 2a to 2d, show the linear regression between  $K_d(\text{PAR})$  versus TSS for the supplied core samples. The regression “line-of-best” fit slopes are displayed within the figures. The maximum lab-determined slope of  $0.0716 \text{ (Lmg}^{-1}\text{m}^{-1}\text{)}$  corresponds to the vc06 core sample, while a minimum slope of  $0.0244 \text{ (Lmg}^{-1}\text{m}^{-1}\text{)}$  was determined for core sample vc55.

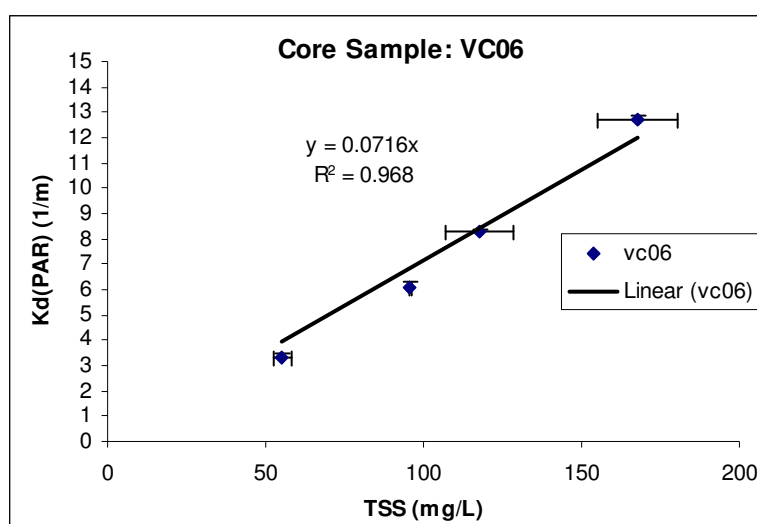


Figure 2a

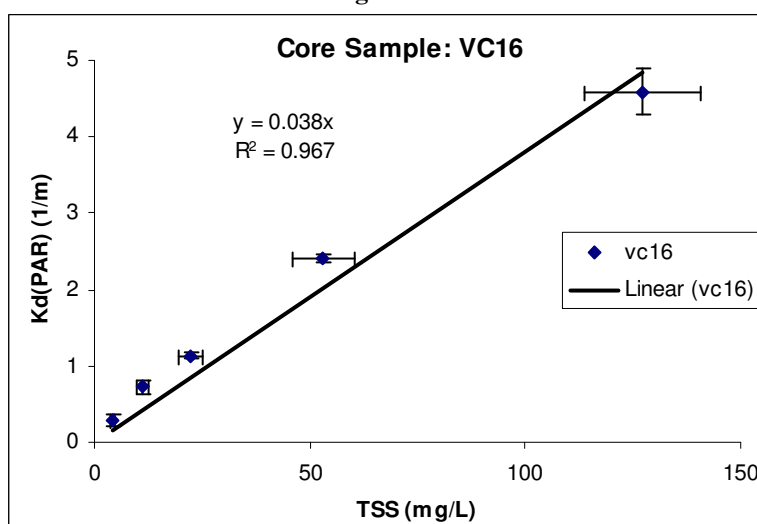


Figure 2b

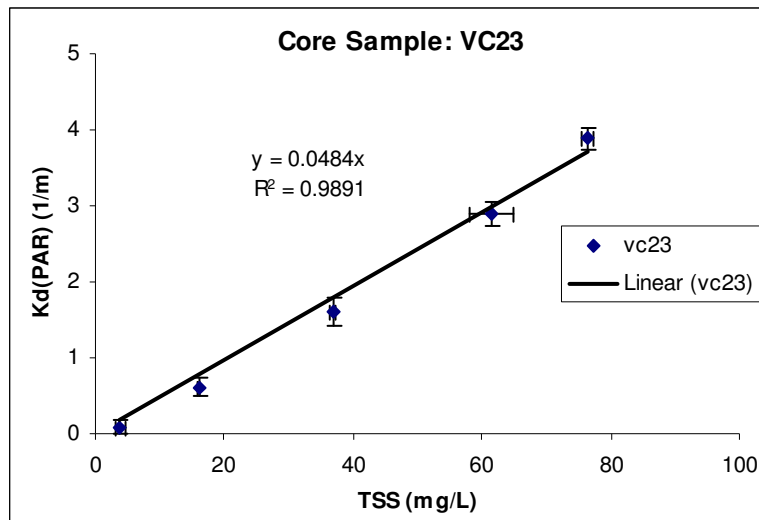


Figure 2c

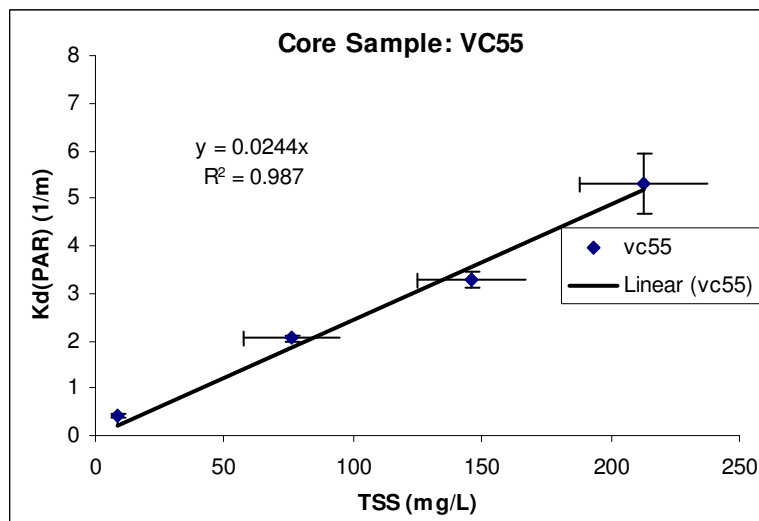


Figure 2d

Figure 3, shows the combined  $K_d(\text{PAR})$  vs TSS relationship applicable for a TSS concentration range of 0 – 80 mg/L.

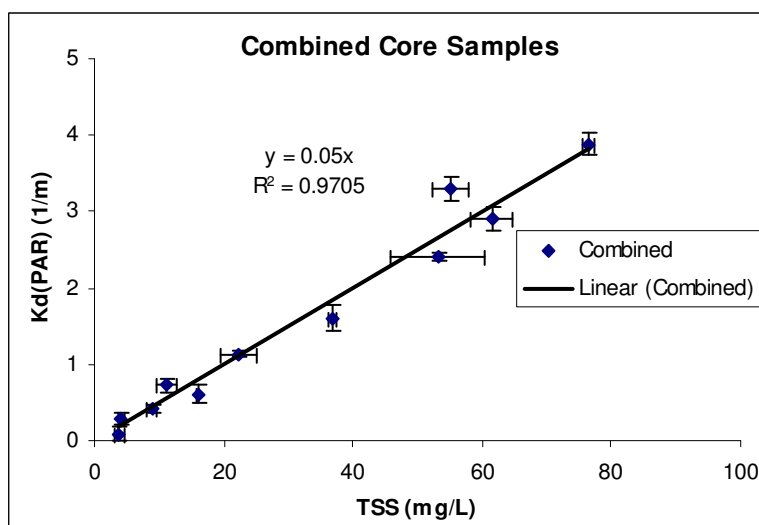


Figure 3

**DISCUSSION:**

The  $K_d(\text{PAR})$  values determined in this study correspond to the contribution of sample sediment cores only. To determine a total light attenuation as applicable in the field, one must add the attenuation coefficients of seawater, phytoplankton, Chromophoric Dissolved Organic Matter (CDOM) and any other in-water constituent with size fraction smaller than approximately 0.5  $\mu\text{m}$  which may also attenuate light.

$$\begin{aligned}K_d^{\text{Total}}(\text{PAR}) &= K_d^{\text{Water}}(\text{PAR}) + K_d^{\text{TSS}}(\text{PAR}) + \dots \\ &= 0.098(\text{m}^{-1}) + K_d^{\text{TSS}}(\text{PAR}) + \dots\end{aligned}$$

Where 0.098  $\text{m}^{-1}$  is taken from Smith et.al (1989).

[http://www.nospam.aslo.org/lo/toc/vol\\_34/issue\\_8/1673.pdf](http://www.nospam.aslo.org/lo/toc/vol_34/issue_8/1673.pdf)

**CONCLUSION:**

The linear relationships of light attenuation and TSS for the 4 core sediment samples were determined using the in-lab approach. The  $K_d(\text{PAR})$  versus TSS slope values are 0.072 ( $\text{Lmg}^{-1}\text{m}^{-1}$ ), 0.038 ( $\text{Lmg}^{-1}\text{m}^{-1}$ ), 0.048 ( $\text{Lmg}^{-1}\text{m}^{-1}$ ) and 0.024 ( $\text{Lmg}^{-1}\text{m}^{-1}$ ) for core sediment samples vc06, vc16, vc23 and vc55, respectively. The light attenuation versus sediment concentration slope for the combined core sediment samples was determined to be 0.05 ( $\text{Lmg}^{-1}\text{m}^{-1}$ ) for a concentration range between 0 and 80  $\text{mg/L}$ .