The Relationship between Dissolved Organic Carbon and Ultra Violet Radiation in Vancouver Island Streams

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Abstract

Dissolved organic carbon (DOC) offers aquatic organisms some protection from the damaging effects of ultraviolet radiation (UVR). Prior to this study, it was unclear how various land uses impacted DOC, and thus UVR absorbance, in aquatic ecosystems on Vancouver Island. This study investigated 10 waterbodies over a three year period (2002-2005) in order to obtain a better understanding of these relationships and how they vary between the Island's ecoregions. This data will contribute to the eventual development of a UV Sensitivity Index for the Island. DOC and UVR attenuation data showed a significant correlation ($p<0.05$), with seasonal peaks in these parameters corresponding to peak rainfall periods. Concentrating on the vulnerable March 1 to October 1 period, differences between ecoregions and individual waterbodies were observed. Specific UV absorbance (SUVA) values were useful in linking general land use impacts to DOC quality and UVR attenuation. However, probably due to the variety and low number of waterbodies studied, these land use relationships were not statistically significant. Due to naturally occurring high quality/large amounts of DOC, aquatic ecosystems within the Nahwitti Lowland and Leeward Island Mountains ecoregions are not prone to spring and summer UVR damage at levels of concern. Aquatic ecosystems within the Nanaimo Lowland watersheds are at risk due to moderate-poor UVR attenuation in spring and summer. Within this ecoregion, sites having several anthropogenic land uses are especially vulnerable to damage from UVR. Windward Island Mountain sites appear to have naturally low levels and/or quality of DOC, thus are also of concern for damage from UVR in the March 1 to October 1 period. To address data gaps in this dataset, future studies should include at least three waterbodies per ecoregion, more detailed forest harvesting data, sampling of in-stream parameters and sampling of site characteristics. As well, fulvic acid, aromaticity and degradation history of the DOC in streams should be examined. Further investigation regarding specific land uses should focus on several watersheds with similar land uses, with agriculture and forest harvesting as a priority. Stream order of the sample site must also be considered.

Introduction and Background

With ozone depletion, ultraviolet radiation (UVR) and its damaging effects have become an increased hazard to all forms of life, even in aquatic ecosystems. In aquatic systems, dissolved organic carbon (DOC) can effectively shield streambeds from the damaging radiation through attenuation of UVR (Kelly *et al.,* 2001; Brooks *et al.,* 2005; Maloney *et al*. 2005). DOC is only one of many factors contributing to stream health, and is itself influenced by several factors, including a variety of land uses and disturbances. Forest harvesting, agriculture, mining and urban development, amongst other disturbances, can influence the quality and quantity of DOC. These influences can be seen at the watershed scale, in the riparian zone and in the water itself. On Vancouver Island, the extent to which various natural and anthropogenic land uses impact DOC and how this varies between the Island's ecoregions is still unclear. A better understanding of these relationships is necessary as a building block for the eventual development of an UV Sensitivity Index for the Island.

Effects of Ultraviolet Radiation in Waterbodies

As a high energy light emitted by the sun, UVR makes up the 100 nm to 400 nm wavelength part of the electromagnetic spectrum. The three kinds of UVR that occur differ in their ability to reach the Earth's surface. UV-C rays (100-280 nm) are completely absorbed by the atmosphere, UV-B rays (280-315 nm) are 90% absorbed by the atmosphere, and UV-A rays (315-400 nm) reach Earth's surface at full strength. For this reason, even though all UVR from 280 nm to 400 nm is of concern, UV-A rays are the most harmful (WHO, 2005) and of the most relevance for this study.

The effects of UVR exposure in waterbodies are numerous and far-reaching. Penetration of UVR into waterbodies can liberate trace metals such as mercury, copper and arsenic which would otherwise be bound to DOC (Perin & Lean, 2004), and can increase the toxicity of polycyclic aromatic hydrocarbons (Zagarese &Williamson, 2001). In addition, exposure to UVR can damage living tissue, causing a variety of problems such as DNA lesions, erythema, and photosynthetic inhibition (Brooks *et al.*, 2005). UVR exposure can also affect mobility and orientation of phytoplankton and, combined with other effects, can lead to decreased primary productivity and biodiversity (Rae *et al*., 2001a).

Aquatic effects of UVR can be seen at many trophic levels. The accrual of lotic algae can be constrained, algal species composition can be changed (Kelly *et al.*, 2001), and growth and photosynthesis of benthic diatom communities can be reduced (Bothwell *et al.*, 1994). However, due to impacts on algal grazers, algae often accumulate more in UVR-exposed environments than UVR-shielded ones. Total invertebrate biomass, especially populations of larval chironomids, is reduced by UVR. This allows algae to accumulate more readily (Bothwell *et al.*, 1994; Kelly & Bothwell, 2002). The effects can be substantial; when shielded from UVR, *Dicosmoecus sp.*, the dominant grazer in many streams, can increase over twenty-fold in number (Kelly & Bothwell, 2002). This will have effects throughout the ecosystem and could change the structure of the food chain.

Salmon and other fish are also affected by UVR. Increases of UVR due to stratospheric ozone depletion have been suggested to be a cause of large declines in fish populations (Walters & Ward, 1998). Coho salmon alevins and two-month-old coho juveniles both exhibit shade-seeking behaviour and selective avoidance of UVR, particularly UV-A (Kelly & Bothwell, 2002). This is presumed to be a mechanism of defence against the harmful effects of this radiation.

Dissolved Organic Carbon

Role with Respect to Ultraviolet Radiation

As organic matter that is broken down and dissolved into water, DOC and its correlate, dissolved organic matter (DOM), play an essential role in a broad range of processes in aquatic environments (Belzile, 2002). DOC is the main component of freshwater that attenuates UVR (Kelly *et al.*, 2001; Brooks *et al.*, 2005; Maloney *et al*. 2005). Attenuation of UVR by DOC is the process by which a radiation wave is decreased in intensity due to the absorption of its energy (Wetzel, 2001). There is an observed pattern between DOC concentration and UVR attenuation (Sommaruga, 2001) and in some experiments, the two are significantly related ($p<0.001$) (Brooks *et al.*, 2005; Laurion *et al*., 2000; Morris *et al*. 1995; Rae *et al*. 2001b). As much as 80-90% of UVR attenuation is due to DOC (Morris *et* *al*., 1995; Rae *et al.* 2001b), and small reductions in DOC concentration can lead to significant increases in UVR penetration (Rae *et al.* 2001b).

In water, UVR can only penetrate to a certain depth because the DOC in the water column acts as a screen. When water levels are high, this prevents the harmful radiation from reaching the streambed. When water levels drop, as in the summer months, UVR can penetrate to the bottom of the stream, causing damage to benthic organisms. To compound the problem of shallow water levels, UVR is most intense in the summer months when the sun's angle with the earth is greatest (Diffey, 1991). Due to the protection it offers from UVR, DOC concentration affects the biodiversity and abundance of stream organisms. One study concluded that streams with a DOM concentration of less than 5 mg/L could be most vulnerable to potential future increases in UVR intensity or decreases in DOM (Kelly *et al.*, 2001).

Despite the observed relationship between DOC and UVR attenuation described above, DOC alone is not enough to predict UVR attenuation (Brooks *et al.*,2005). Variables such as local hydrology, annual precipitation, light availability, stream and riparian width, water depth, solar arc and stream aspect are important to consider when determining whether DOC provides the waterbody with adequate protection from UVR (Brooks *et al.*, 2005). Also, Brooks *et al.*, (2005) note that the source of DOC greatly affects the amount of UV attenuation that occurs.

<u>Sources and Quality of Dissolved Organic Carbon</u>

In temperate freshwater systems, terrestrially derived (allochthonous) DOC is very important (Croue, 2004). Decomposing leaves and woody debris in the catchment area produce pigmented DOC that is flushed into waterbodies (Gergel *et al.*, 1999) causing water colour to be yellow to dark brown (Pearl, 2005). Contrastingly, in-stream and algal-sourced (autochthonous) DOC that comes from phytoplankton and aquatic macrophytes is not pigmented and makes up only a small percentage of the total DOC in natural waters (Gergel *et al.,* 1999).

DOC is comprised of soluble carbohydrates, amino acids, and other acids including fulvic acid. Fulvic acid is the main component of DOC that causes UVR attenuation. This acid is part of the humic structure in rich composting soil and is formed when beneficial microbes work to break down decaying plant matter in a soil environment with adequate oxygen (Brooks *et al.*, 2005). While fulvic acid can be formed from algal sources, the terrestrial sources are less easily degraded and more effective at absorbing UVR (Brooks *et al.*, 2005; McKnight *et al*. 1994). Thus, terrestrial-derived DOC is a better indicator of UVR attenuation than algal-derived DOC. Heavily forested catchments, producing a large amount of terrestrial organic matter, supply more fulvic acid and thus coloured DOC (having a higher degree of aromaticity) to waterbodies than do sparsely forested catchments (Rae *et al*., 2001b).

Fulvic acid is a high molecular weight DOC (Rae *et al*. 2001b) and can be photochemically degraded through UV exposure (Kouassi *et al*., 1990; Gjessing, 1980; Strome and Miller, 1978). This produces low molecular weight DOC that is less able to attenuate UVR (Croue, 2004; Morris & Hargreaves, 1997; Lindell *et al*. 1995, Stewart and Wetzel, 1980). High molecular weight DOC are generally more hydrophobic, have greater aromatic components, decreased mobility and diffusion, and are less susceptible to biological utilization than are low molecular weight DOC (Wetzel, 2001). Higher aromatic character and molecular weight DOC is indicated through higher Specific Ultraviolet Absorbance (SUVA) values (Croue, 2004; Rae *et al*., 2001b). SUVA is a better indicator of the reactivity of the aromatic compounds making up aquatic humic substances than it is for DOC presence (Weishaar *et al.* 2003). Thus, SUVA can be used as a gauge for the quality of the DOC, in particular the humic and fulvic acid components.

Levels of DOC fluctuate naturally, based primarily on season. However, urban development, agriculture, riparian removal and forest harvesting can disrupt these natural cycles by removing the source for DOC or by changing drainage patterns. If vegetation is removed, there is no longer a source for terrestrial DOC and the concentration will decrease. In the case of forest harvesting, there will be a temporary increase in DOC concentration as the residual debris decomposes (Collier & Bowman, 2003). Once this process is complete, there will likely be a decrease in DOC levels until the vegetation re-establishes itself and can once again provide a source for DOC (Collier & Bowman, 2003). Agriculture and pasture development creates longer, slower flowpaths that increase the possibility of shifts in DOC content, composition and inorganic nutrient concentrations. Such shifts can result from an increase in exposure to sunlight that allows for greater potential of photolysis (Findlay *et al.* 2001) and thus, lower efficiency in attenuating UVR.

Objectives

The purpose of this study was to analyse UVR and DOC with respect to freshwaterbodies and their DOC source on Vancouver Island, and to better understand these relationships as related to Vancouver Island's ecoregions. Over a three year period (2002-2005), ten streams on Vancouver Island were monitored monthly for UVR absorbance and DOC concentration by Ministry of Environment Impact Assessment Biologists and their partners. Land use data was considered to determine if specific land uses appear to have greater impacts on DOC content and quality than others. Determination of the susceptibility of watersheds based on this data will be used as a building block for development of an UV Sensitivity Index for Vancouver Island.

Methodology

Surface water samples were collected from ten streams, representing four of the five ecoregions on Vancouver Island (Fig. 1, Table 1). An ecoregion is the smallest classification in the British Columbia Ministry of Sustainable Resource Management's widely adopted classification system, and is defined as an area with minor physiographic and macroclimatic or oceanographic variations (Province of B.C., 2001). Watershed characteristics and sampling locations are summarized in Table 1.

Samples, collected in 1 litre plastic bottles, were taken monthly from 2002 to 2005, except at San Juan River where they were taken bi-weekly, and Little Qualicum River where they were taken for only one year. Samples were kept on ice in coolers and shipped to Maxxam Analytics Inc. where they were analyzed for DOC concentration and UVR absorbance at wavelengths of 250 nm, 254 nm, 310 nm, 340 nm, 360 nm, and 365 nm.

Though seasonal trends were summarized, only DOC and UVR data from March 1st to October 1st of each year were used for statistical analysis. These dates were chosen because the impacts of UVR on stream organisms are most pronounced during these months, when the radiation is most intense and the water level is lowest. Regression analyses were conducted to determine the ability to predict UV-A absorption from UV-C absorption, and the ability to predict UVR absorbance from DOC concentrations.

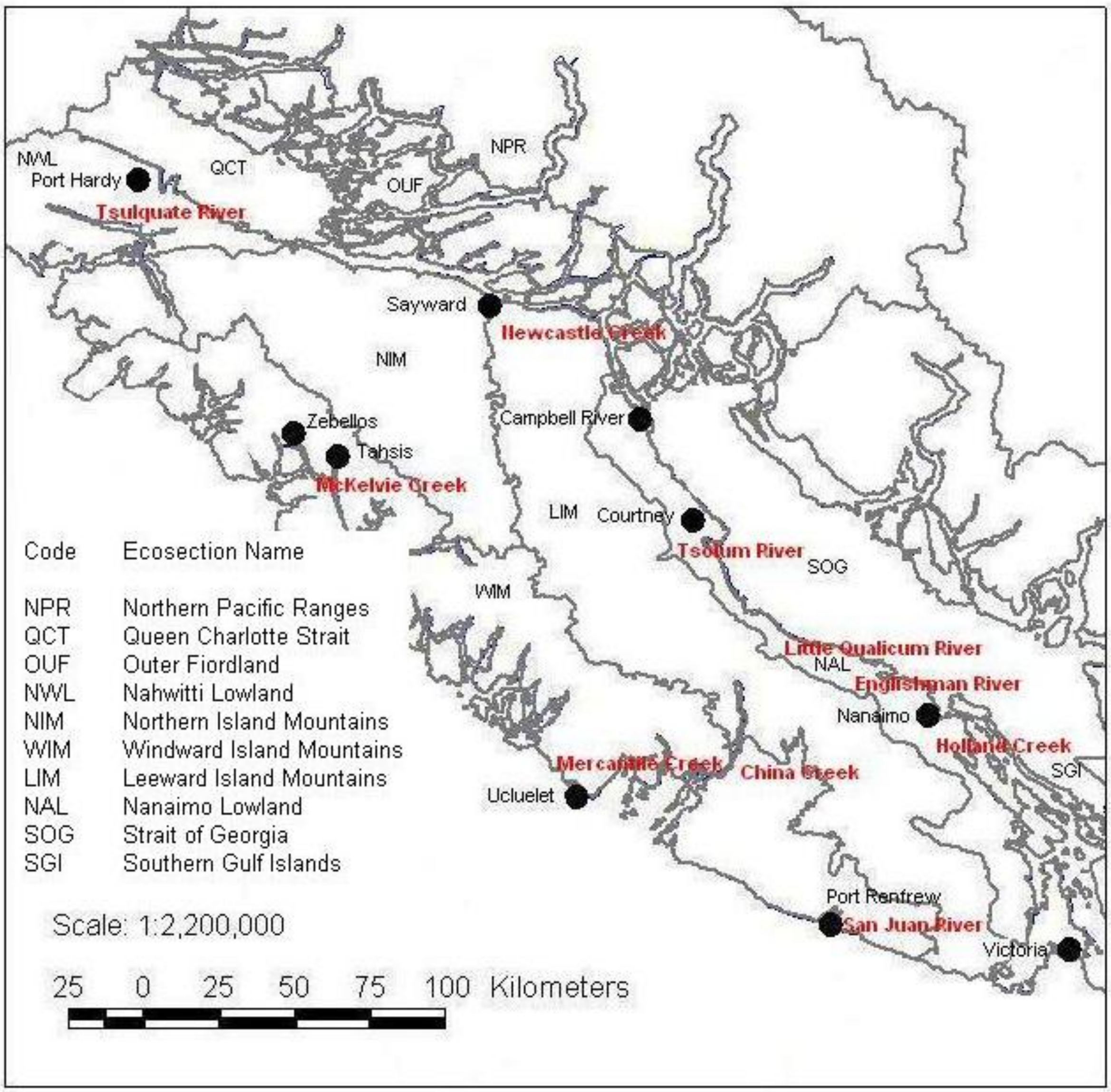

Figure 1. Vancouver Island ecoregions and study site locations.

Table 1. Name, ecoregion, watershed size, dominant land use, and geographic location for ten Vancouver Island study sites sampled for UVR absorbance and DOC concentration, 2002-05. U/s=upstream, d/s=downstream.

Site	Drinking water supply for:	Ecoregion	Watershed size (ha)	Dominant Land use	Latitude	Longitude	Sample site	Years sampled
Tsulquate River	Port Hardy	Nahwitti Lowland	4 517	mature forest	50°43'46"	127°31'45"	impoundment and intake area	3
McKelvie Creek	Tahsis	Windward Island Mountains	2 144	logging, mature fores	49°50'40"	126°51'00"	impoundment and intake area	3
Mercantile Creek	Ucluelet	Windward Island Mountains	1 164	logging	48°57'59"	125°32'30"	impoundment and intake area	3
China Creek	Port Alberni	Windward Island Mountains	6 500	mature forest	49°10'41"	124°45'42"	impoundment and intake area	3
San Juan River	N/A	Windward Island Mountains	58 000	logging	48°27'32"	123°24'43"	approx. 1 km u/s of tidal influences	3
Newcastle Creek	Sayward	Leeward Island Mountains	896	mature forest	50°22'31"	125°57'50"	impoundment and intake area	3
Tsolum River	N/A	Nanaimo Lowland	25 800	logging, mining	49°48'37"	125°11'57"	500 m d/s of Murex Creek confluence	3
Little Qualicum River	infiltration wells for Town of Qualicum	Nanaimo Lowland	24 880	agriculture, logging, urban, wetlands	49°21'38"	124°29'05"	just u/s of infiltration wells	1
Englishman River	Parksville	Nanaimo Lowland	32 400	agriculture, logging, urban	49°18'04"	124°16'32"	lower watershed, d/s of Hwy 1, approx. 1 km u/s of tidal influence	3
Holland Creek	Ladysmith	Nanaimo Lowland	265	logging, urban	48°58'47"	123°48'30"	impoundment and intake area	3

In data analysis, values below minimum detectable limits (MDL) were approached differently depending on percentage of values for a given parameter below MDL. If less than 15% of values were below MDL (UV-C and DOC data), each below-MDL value was replaced with a value of half the MDL. When greater than 50% of values where below MDL (UV-A data), a Tobit analysis with LIFEREG was performed in SAS to fit a regression model. The model for the UV-C and UV-A data used the equation: log (UV365)=log(k) + c*log(UV250) where k was a multiplicate constant and c was a power law. At a given site, data was not used from any given sampling date on which the parameters considered were both below MDL.

Historical land use records were gathered from previous reports (Carmanah Research, 1997; Wilson, 2003) and recent changes were noted. A more in-depth analysis of percent land use within the watershed was conducted via the Ministry's online mapping tools (Land Information BC, 2005): iMapBC v1.1 and the Land and Resource Data Warehouse Catalogue (LRDWC). The 'measure area' analytical tool was used to determine the size of various land use polygons within the watershed, and these values were converted to percent values. Land use percentage value data were thus updated only to the same degree to which the map layers available were updated (Table 2). Land use data is based on polygons as determined by information analysts using a variety of analytical techniques, mostly based on Landsat 5 image mosaics.

Table 2. Layers used to determine land use on government mapping site

Map Layer used	**Last updated**
Water (iMapBC)	2002
Community Watersheds (iMapBC)	2003
Present Land use(iMapBC)	1997
Cutblocks (LRDWC)	2003

Using regression analyses, land use percentages in each watershed were then analyzed with median seasonal UV attenuation and DOC values at the sample site considered, e.g. all watersheds with recent land use were included in one regression analysis. In addition, SUVA was obtained through the formula:

*SUVA (L/mg-M) = UV absorbance @ 254nm (cm^{-1}) / DOC (mg/L) * 100 cm/M*
(Potter & Wimsatt, 2005)

to more readily show the differences in absorbance levels for each individual site. SUVA is an expression of the attenuation of UVR by DOC. This simple formula provides a value that more obviously reveals the attenuation of UVR per unit of DOC. The equation was applied to all data and then a median was found for each site. Table 3 summarizes the expected nature of the natural organic matter as related to the SUVA value (Edzwald and Tobiason 1999).

Table 3.. Expected nature of natural organic matter as related to the SUVA value (from Edzwald and Tobiason, 1999).

SUVA	Nature of Natural Organic Matter (NOM)
<2	Mostly non-humics, low hydrophobicity, low molecular weight
2-4	Mix of aquatic humics and other NOM, mix of hydrophobic and hydrophilic NOM, mix of molecular weights
>4	Mostly aquatic humics, high hydrophobicity, high molecular weight

Results

Ultra Violet Radiation

Considering data throughout the year, UVR absorbance levels varied seasonally, with the highest peaks occurring in the fall and slightly lower peaks occurring in the spring (Appendix 1 Figs. 10 – 29 and Appendix 2 Tables 4 - 13). Observed peaks in UV-A (315-400 nm) absorbance data coincided with UV-C (100-280 nm) absorbance data peaks.

As mentioned in the introduction, UV-A radiation is of most importance to this study. However, 50% of UV-A absorbance values were below MDL (0.01 AU/cm), whereas the majority of the UV-C absorbance data points were above MDL. It was thus easier to see patterns and trends in the UV-C absorbance data. According to the methodology for this many values over MDL, a LIFEREG analysis was performed. The LIFEREG analysis results indicated c=0.87 (standard error=0.08 and a 95% confidence interval between 0.71 and 1.03). With a confidence interval covering 1, there was no evidence that "c" differed from 1. Thus, according to the formula given in the methodology, UV-A readings were predicted to be 1/8.3 of the UV-C readings. Removal of two anomalous data points (Englishman River Sept 4, 2005 and Tsulquate River Sept 2, 2005) resulted in only a slight change of this value to 1/8.5. Thus, the patterns observed in UV-C absorbance data could be also assumed to occur in the UV-A absorbance data.

Supporting this, a regression analysis of March 1 to Oct 1 UV-C and UV-A absorbance data showed that UV-A related significantly ($p<0.05$) and linearly ($r^2 = 0.813$) to the UV-C data (Fig 2). Watershed specific UVR absorbance regression analyses (not illustrated) also showed significant relationships ($p < 0.05$) for all waterbodies except for those with most data points below MDL or insufficient data points (China Creek, Holland Creek, Little Qualicum River).

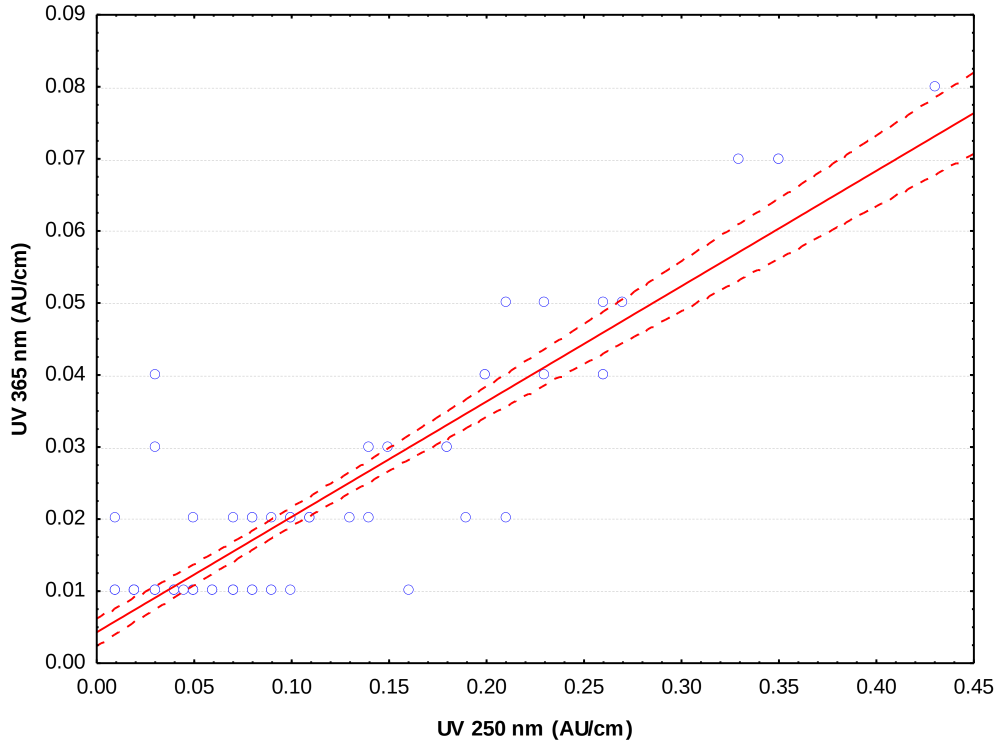

Figure 2. Regression analysis of UV-C (250 nm) and UV-A (365 nm) (samples collected between March 1st and October 1st of 2002-05) showing a 95% confidence interval. This analysis excluded points where both datasets were below MDL and removed the anomalous data point at Englishman River Sept 4, 2005 and Tsulquate River Sept 2, 2005. $r^2 = 0.813$, p = 0<0.05; y = 0.004 + 0.160*x

March 1- Oct 1 UVR absorbance data showed a lot of variability between sites and between ecoregions (Fig. 3). The median March 1 to October 1 UVR absorbance levels at 250 nm (UV-C) ranged from a high of 0.260 AU/cm in the Tsulquate River to a low of 0.015 AU/cm in McKelvie Creek. Sixty percent (6 of 10) of sites had median values between 0.030 and 0.060 AU/cm.

Tsulquate River was the only watershed studied within the Nahwitti Lowland, and had consistently higher UVR absorbance values than all other watersheds studied. Other than Tsulquate River, the highest median level was 0.110 AU/cm in Newcastle Creek (Leeward Island Mountains), also the only watershed studied within its ecoregion. The Nanaimo Lowland sites (Tsolum River, Holland Creek, Englishman River and Little Qualicum River) had moderate levels and median values ranging from 0.040 to 0.070 AU/cm. Within the Windward Island Mountains, Mercantile Creek had moderate levels and a median of 0.050 AU/cm, but McKelvie Creek, China Creek and the San Juan River had very low levels and median values ranging from 0.015 to 0.03 AU/cm.

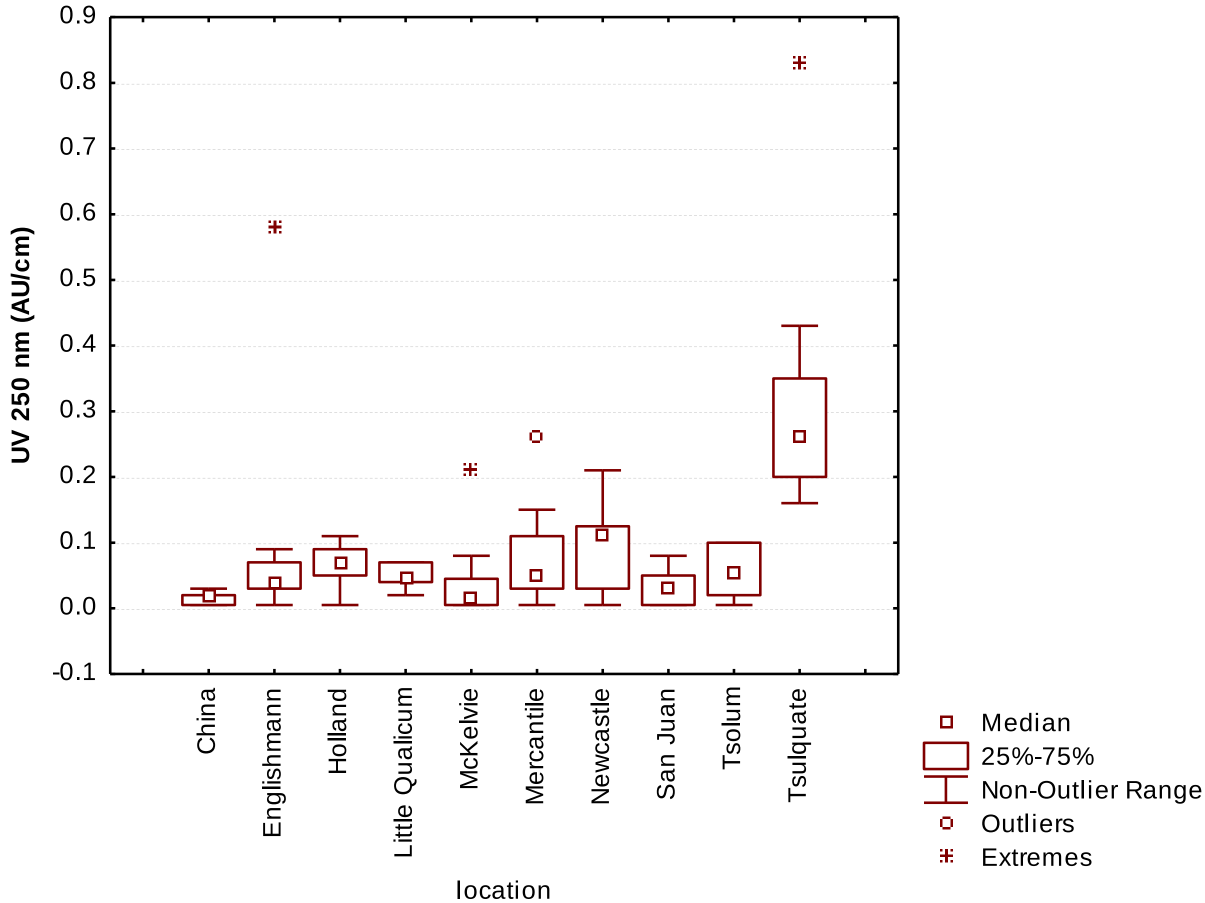

Figure 3. UVR absorbance data summary (250 nm only) for samples collected between March 1st and October 1st, 2002-05.

Dissolved Organic Carbon

Considering both yearlong data and March 1 – Oct 1 data alone, sites tended to show the same trends in DOC concentrations as observed in UVR absorbance levels (Appendix 1 Figs. 11-30 and Appendix 2 Tables 4 –13). Like UVR absorbance levels, DOC levels varied seasonally, with peaks occurring in both the fall and the spring. There was a lot of variability both between sites and between ecoregions.

Median March 1 to October 1 DOC levels (Fig. 4) ranged from a high of 6.00 mg/L in the Tsulquate River, to a low of 0.80 mg/L in China Creek. Sixty percent (6 of 10 sites) had median values between 1.00 and 2.50 mg/L.

Other than the Tsulquate River (Nahwitti Lowland) site, the highest median level was 2.90 mg/L at Newcastle Creek (Leeward Island Mountains). Both these values were relatively high (>=2.90 mg/L) in relation to those observed at other sites; Tsolum River, Holland Creek, Englishman River, and Little Qualicum River (all Nanaimo Lowland sites) had moderate DOC levels (1.25-2.10 mg/L); and San Juan River, China Creek and McKelvie

Creek (all Windward Island Mountains) had low DOC levels (<1.10 mg/L). Only one Windward Island Mountains site, Mercantile Creek, had moderate DOC levels (median=2.00 mg/L).

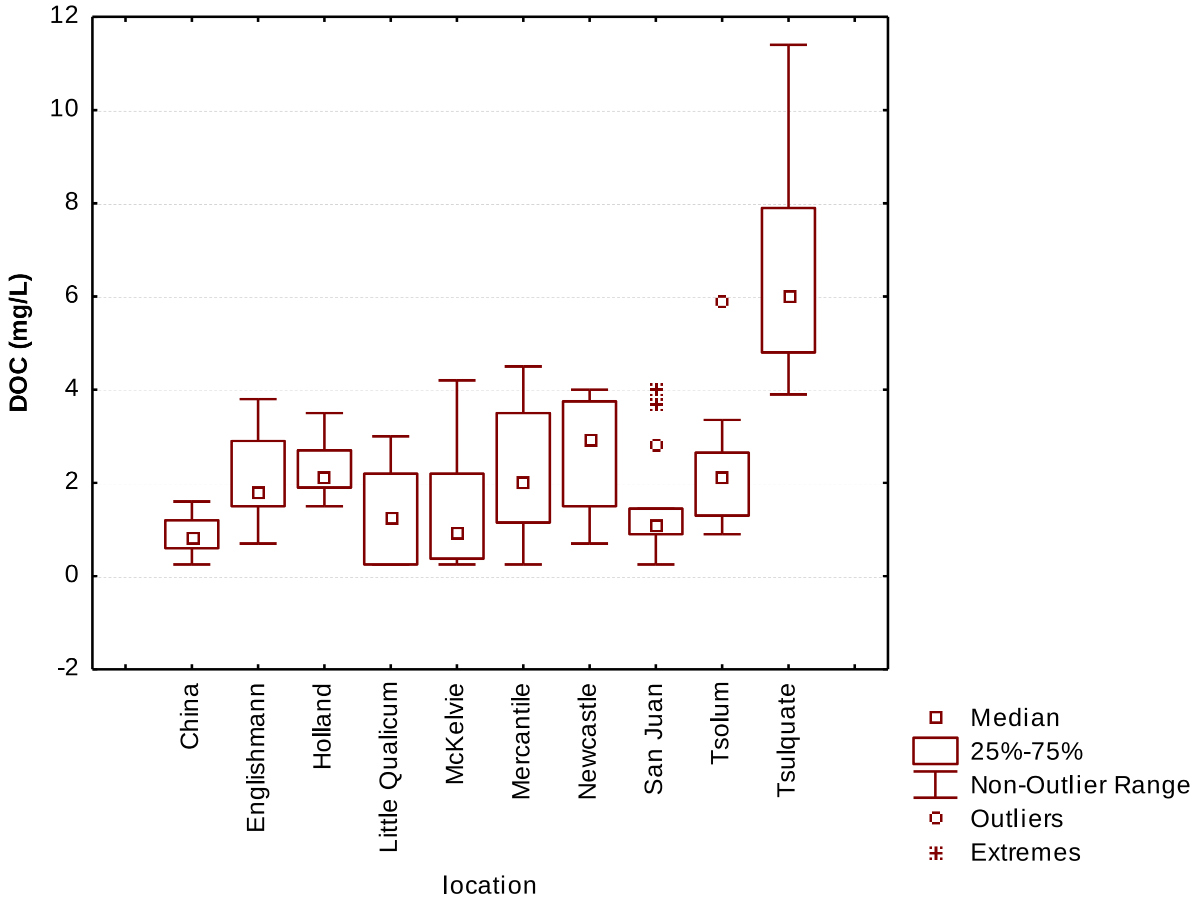

Figure 4. DOC data summary for samples collected between March 1st and October 1st, 2002-05.

Plotting all DOC data by month (Fig. 5) shows a slight decrease in DOC in all waterbodies with the progression of summer.

A regression analysis of DOC and UV-C absorbance (Fig. 6) showed a significant ($p<0.05$) positive relationship ($r^2 = 0.632$) between these two factors. However, when performing the regression analyses by waterbody (Fig. 7), only three watersheds (Tsolum, McKelvie and Englishman) were significantly related.

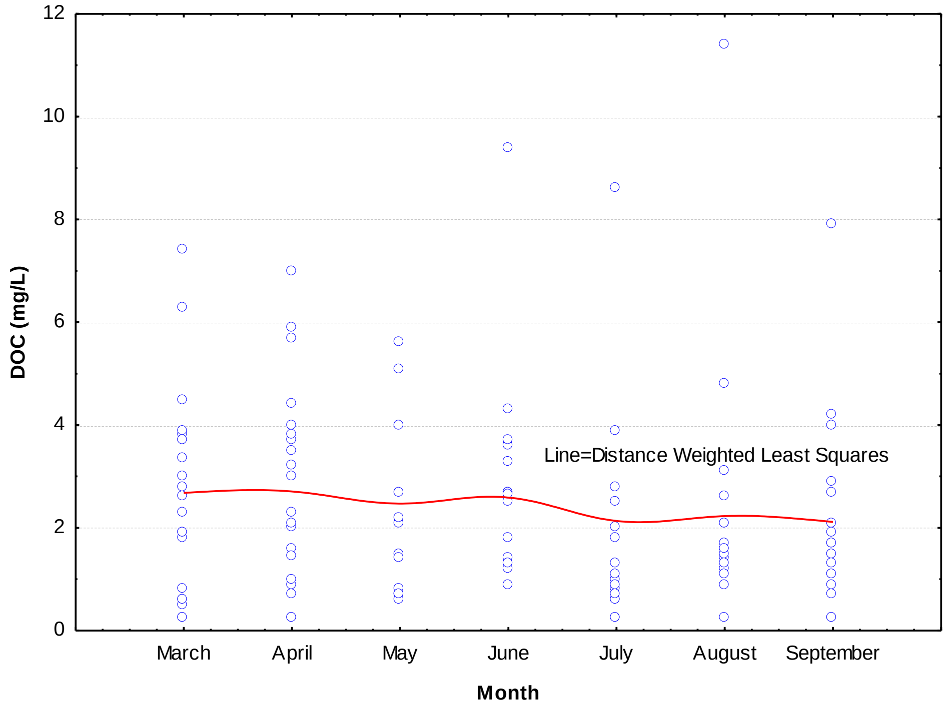

Figure 5. Plot of all DOC data by month (March-October 1, 2002-2005) of DOC showing a line fitting the distance of weighted least squares. This analysis excluded the anomalous data point at Englishman River Sept 4, 2005 and Tsulqate River Sept 2, 2005.

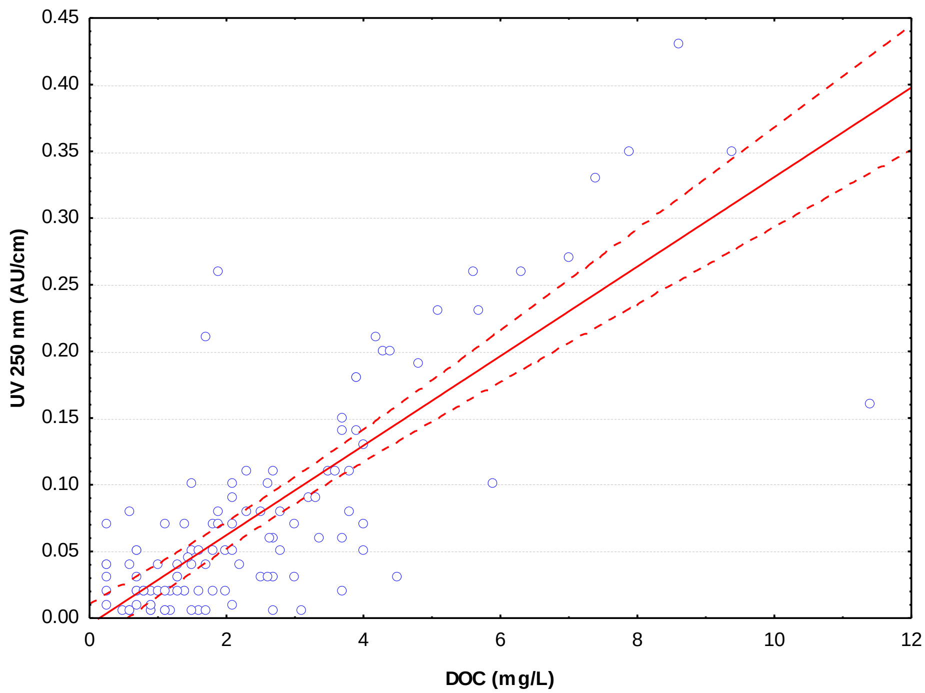

Figure 6. Regression analysis of all data (March-October 1, 2002-2005) of DOC and UVC (250 nm) showing a 95% confidence interval. This analysis excluded points where both datasets were below MDL and removed the anomalous data point at Englishman River Sept 4, 2005 and Tsulqate River Sept 2, 2005. $r^2 = 0.632$, $p<0.05$, $y = -0.005 + 0.034*x$

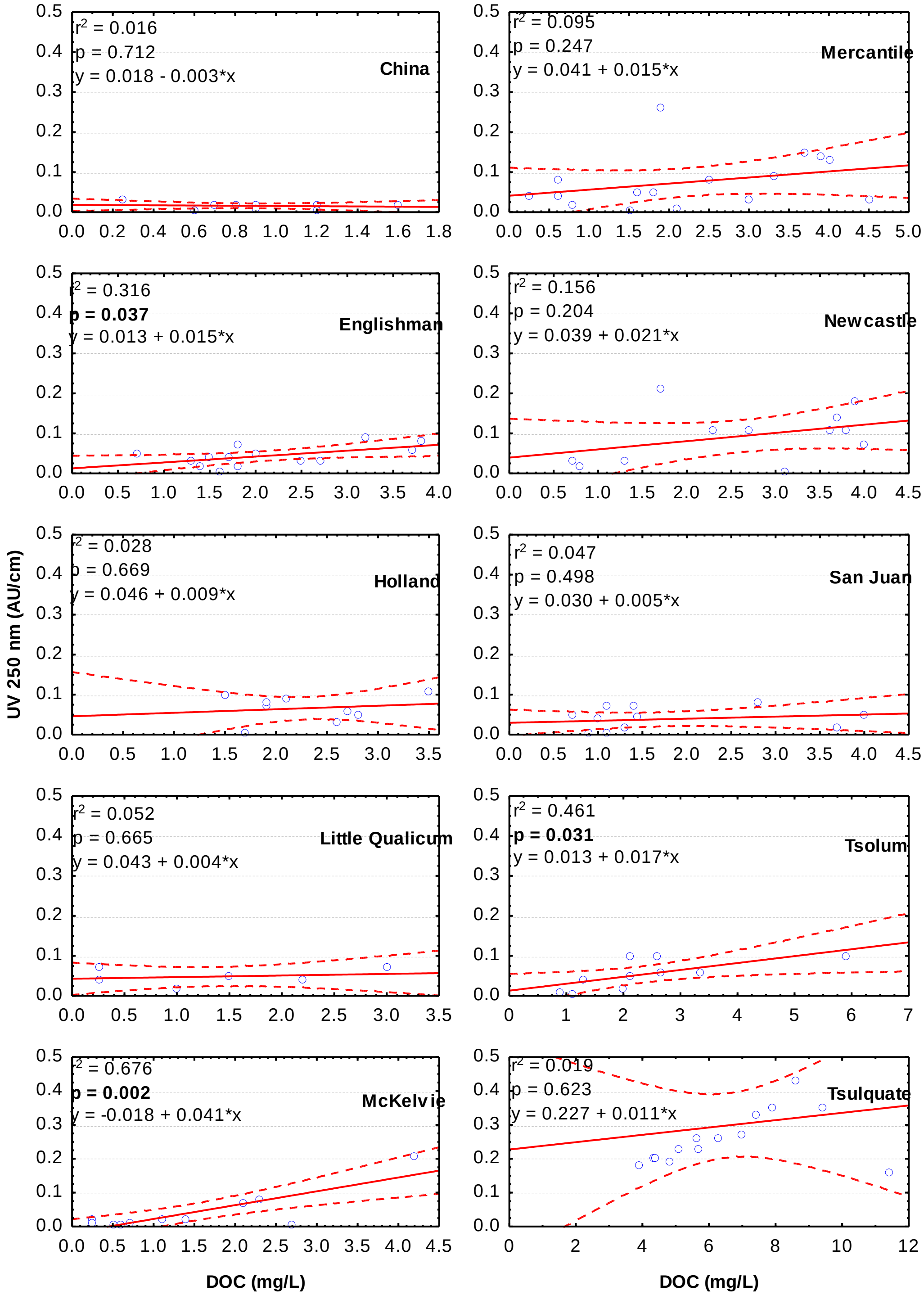

Figure 7. Regression analysis, by waterbody, of DOC and UVC (250 nm) showing a 95% confidence interval. r^2, p-values and trend line equation are shown on each graph. Note X-axis scales are different. This analysis excluded points where both datasets were below MDL and removed the anomalous data point at Englishman River Sept 4, 2005 and Tsulqate River Sept 2, 2005.

Specific Ultra Violet Absorbance (SUVA)

The Tsulquate was the only watershed having high median SUVA of >4 L/mg-M (Fig. 8). Tsolum, Englishman and China watersheds were the only ones with a low SUVA of <2 L/mg-M. The remaining watersheds had moderate median SUVA values ranging between 2-4 L/mg-M. Of these moderate SUVA sites, Newcastle, Mercantile, San Juan and Holland had median SUVA values above 3 L/mg-M, and will be referred to from here on as moderate-high SUVA sites. Little Qualicum River had two very high SUVA values of 16 and 28 L/mg-M from days when the DOC level was below MDL, yet the median attenuation was still lower than 3 L/mg-M. The narrowest range of results was at Tsulquate River, with most of the results falling between 3.7 and 5.0 L/mg-M. With the exception of Little Qualicum and Tsulquate, all sites had some non-extreme values below 2 L/mg-M.

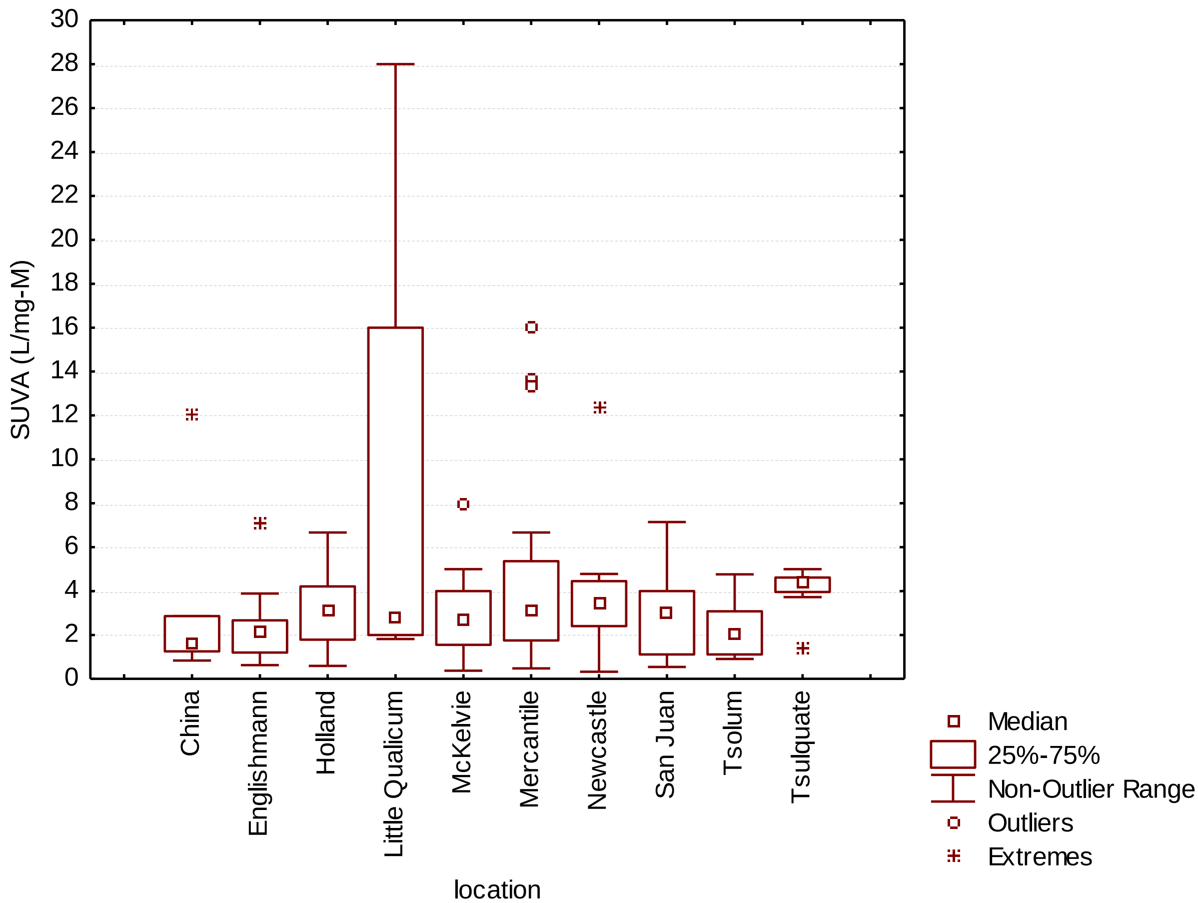

Figure 8. SUVA data summary for samples collected between March 1st and October 1st, 2002-05.

Land use Data

Percentage land use data for each waterbody is summarized in Fig.9.
Tsulquate River - The Tsulquate River is dominated by old forest (83%). The river flows through 15 km of old forest, and 500 m of young forest (7.5%). Some tributaries originate in marshes, and there is some recent logging (4.4%) near the sampling site. Open freshwater (lakes/wetlands) also makes up a part of this watershed (5.1%). There are no agricultural or urban impacts. This watershed is in an area where naturally occurring tannins and lignins result in darkly tinted water.

McKelvie Creek - McKelvie Creek is dominated by old forest (79%). There is some recently logged forest observed surrounding the sample site. As this was not on the LRDWC, it is more recent than 2003. Upstream, where the tributaries originate, there is a combination of mature forest, sub alpine (3.7%), alpine (17.3%) and glacier. There are no agricultural, urban or wetland impacts.

Mercantile Creek - Mercantile Creek is dominated by young (43.1%) and recently logged (46.6%) forest. There is a 200-300 m wide strip of old forest (10.3%) on either side of the river for 2 km upstream of the sampling site. Beyond this buffer is recently logged forest, and many tributaries also originate in young or recently logged forest. There are no agriculture, urban or wetland impacts.

China Creek - China Creek is dominated by old forest (39.3%). The creek flows through 20 km of young forest (33.2%), and most tributaries originate in recently logged (23.6%) or mature forest. Recent logging commenced upstream of the sampling site in summer 2005, but impacts have not yet been measured. Alpine (1.5%), sub-alpine (2.0%) and open freshwater (0.5%) land use account for small areas inside the watershed. There are no urban or wetland impacts.

San Juan River - The San Juan River is dominated by young (32.1%) and recently logged (44.2%) forest. The river flows through 15 km of young forest, and numerous tributaries flow through young or recently logged forest. Old forest (23.4%), wetlands (0.2%), open freshwater (0.1%) and barren rock surfaces (0.1%) make up the rest of the watershed influencing the San Juan. There are no agricultural or urban impacts.

Newcastle Creek - Newcastle Creek is dominated by old forest (79.8%). Two forks join upstream of the sampling site. One fork flows through 2 km of old forest, and the other flows through old and young forest (16.9%). There is also a section of alpine (3.4%) terrain upstream. There are no agricultural, urban, wetlands or recent logging impacts.

Tsolum River - The Tsolum River is dominated by young forest (65.9%) and recent logging (9.1%). The mine upstream of the sample site is no longer active but continues to impact the river (Deniseger & Kwong, 1996). There are also some agricultural (7.2%), urban (7.4%), old forest (6.7%), residential/agriculture mix (2.2%), open freshwater (0.7%) and wetlands (0.8%) impacts in the watershed. A wetland is just upstream of the sampling site.

Little Qualicum River - The Little Qualicum River has a variety of land use influences including young forest (37.7%), old forest (31.4%), recent logging (21.5%), urban (2.7%), open freshwater (1.9%), alpine (1.9%), recreation (1.0%), barren surfaces (1.0%), and agriculture (0.9%). There are some wetlands upstream of the sample site. This river tends to go subsurface in the lower reaches during the summer low flow period.

Englishman River - The lower watershed of the Englishman River is dominated by young forest (45.4%), recent logging (33.3%), and old forest (14.6%) influences. There are also urban (3.3%), mining (0.2%), open freshwater (0.5%), alpine (1.2%), sub-alpine (0.2%) and agricultural (0.8%) impacts upstream of the sample site. Wetlands (0.4%) comprise small areas in the watershed. The Englishman River flow is regulated through the Arrowsmith Dam in the headwaters.

Holland Creek - Holland Creek is dominated by young forest (93.6%), recent logging (4.5%) and urban impacts (Wilson, 2003). There is a small area of open water (1.9%) and also old forest (0.1%) that rests within the watershed. There are no agricultural or wetland impacts upstream of the sample site.

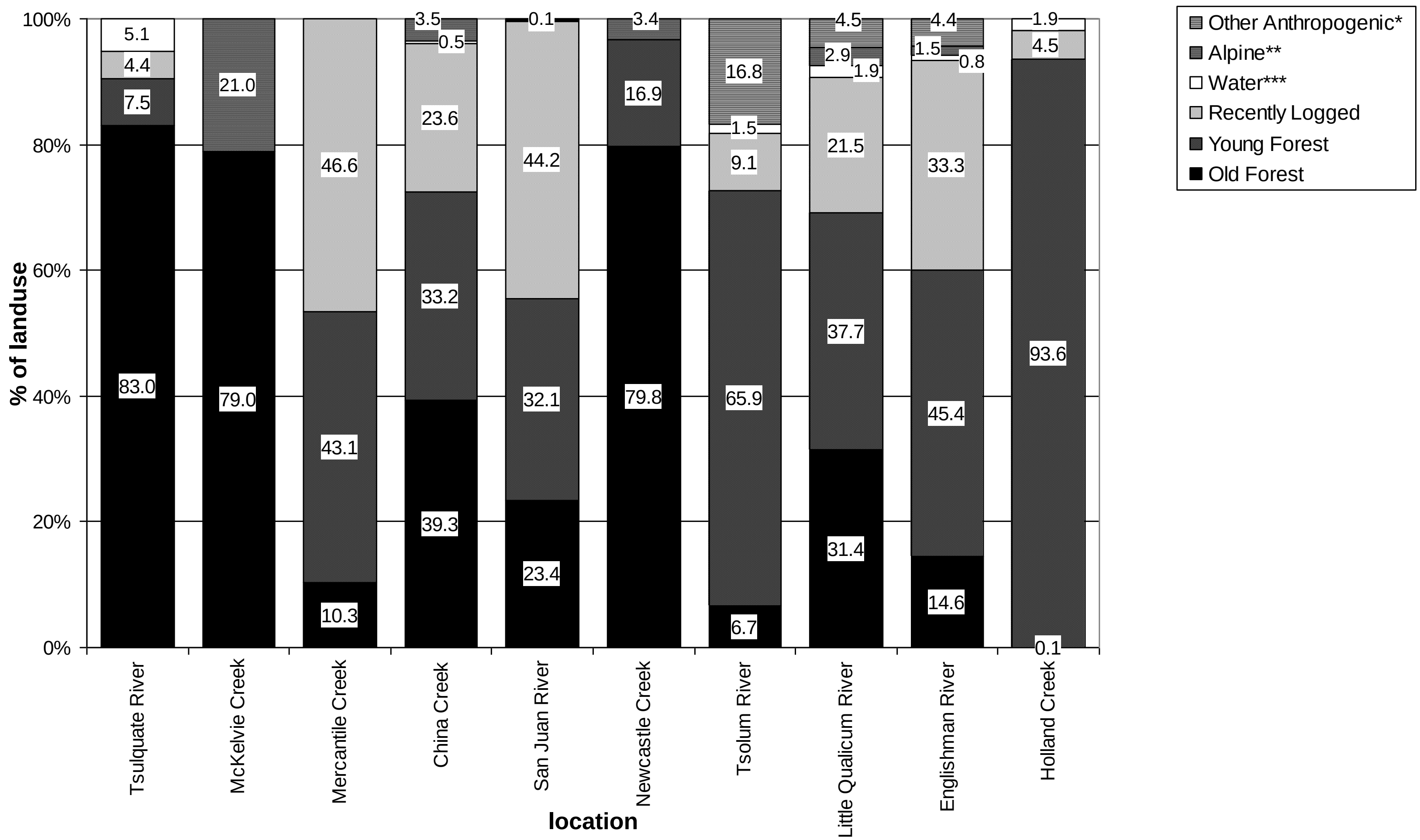

Figure 9. Land use composition (percent) in study watersheds. *Other anthropogenic includes Urban, Agriculture, Mining, Residential/Agricultural Mix and Recreation. **Alpine includes Alpine, Sub-alpine and barren surfaces. ***Water includes wetlands and open freshwater (lakes/wetlands).

Of all land uses considered in this study, only open freshwater (lakes/wetlands) showed a significant ($p<0.005$) relationship to the attenuation of UVR (Fig. 10) and DOC content ($y = 0.9353x + 0.7258$; $r^2 = 0.8325$; $p<0.005$) median seasonal value. However, without the influence of the site at Tsulquate River there was no statistical significance.

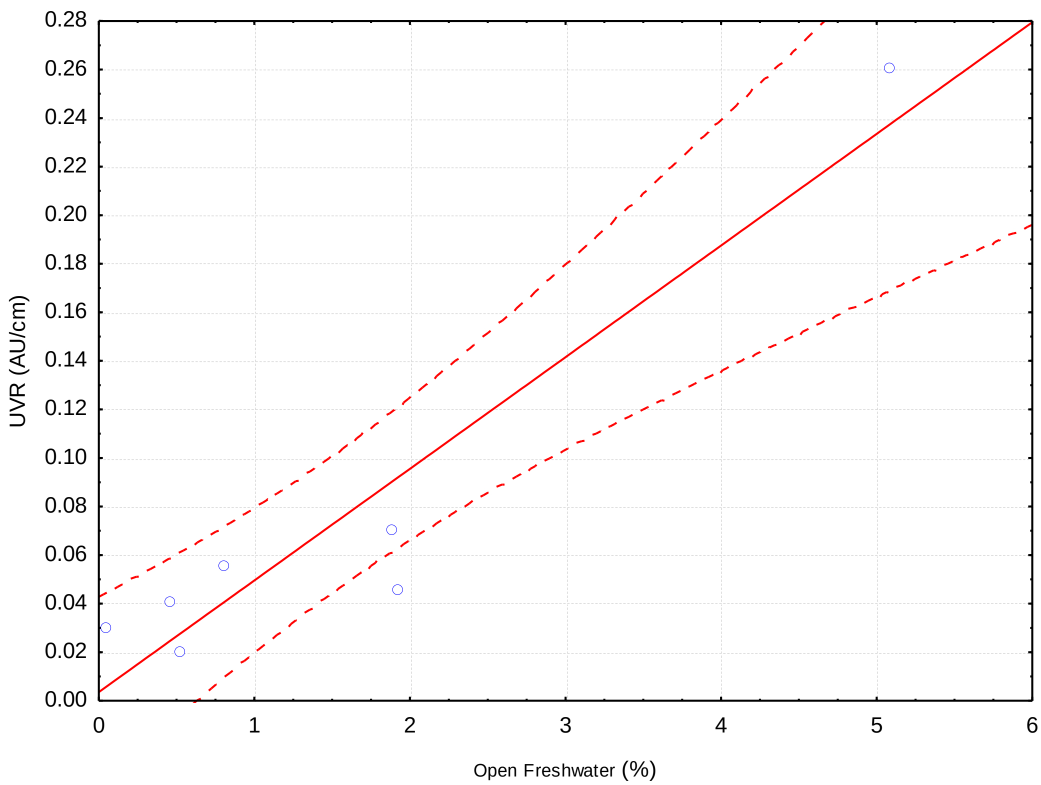

Figure 10. Regression analysis of UVR attenuation and percent of open freshwater in watershed showing a 95% confidence interval. r^2=0.899, p<0.005; y=0.004 + 0.0460*x

<u>Discussion</u>

This dataset has provided a better understanding of UVR susceptibility in the ecoregions examined on Vancouver Island. Similar trends within all ecoregions were observed seasonally with both DOC and UVR. Concentrating on the vulnerable March 1 to October 1 period, differences between ecoregions and individual waterbodies could also be observed. SUVA values were useful in linking general land use to DOC quality. Though land use impacts were apparent, no one landuse could be specifically linked to DOC quality or UVR attenuation.

Because precipitation is the primary mechanism for transporting DOC from the terrestrial source to the waterbody (Brooks *et al.*, 2005), fluctuations in precipitation lead to fluctuations in DOC concentration. In this study, DOC peaks occurred in the fall and spring, and gradually decreased during the summer, coinciding with typical rainfall patterns on Vancouver Island (Environment Canada, 2006). Though river discharge data was not compiled for this study, river flows on Vancouver Island decrease during the summer months, and the DOC results in this study appears to reflect this trend. The first large rainfall after a dry spell tends to flush out much of the DOC that has been accumulating in the riparian zone and catchment area. DOC levels then typically taper off to levels not exceeding the rate at which DOC can be produced (Gergel *et al.,* 1999).

The nearly-simultaneous peaks in DOC concentrations and UVR absorbance suggest that DOC concentration may be causing part or all of the UVR attenuation in these Vancouver Island streams. Regression analyses from this study indicated a significant relationship between DOC concentration and UVR absorbance for all waterbodies combined. This relationship has also been observed in other studies (Bothwell *et al*. 2002, Brooks *et al.*, 2005; Sommaruga, 2001; Laurion *et al*., 2000; Morris *et al*. 1995; Rae *et al*. 2001b).

When considered alone however, seven of the ten waterbodies showed non-significant correlations, suggesting that variation in quality of DOC may affect the attenuation of UVR. In the small datasets available for each watershed, one or two datapoints showing very different attenuations can greatly affect the relationship. Literature states that UVR attenuation cannot be accurately predicted from DOC measurements alone (Lindell *et al.* 1999, Brooks *et al.* 2005). Quality, quantity and nature of DOC are attributed to differences in soil or vegetation type, topography, land uses or other variables. These differences could cause variability in the fulvic acid component of the DOC and thus UVR attenuation of the water (Findlay *et al*., 2001; Rae *et al*. 2001b). Presence of lakes above the sample sites may also strongly influence the DOC present, thus the order of the stream should also be considered in choosing study sites. Bothwell *et al*. (2002) limited data collection to only 2^{nd} order streams in logged watersheds with no upstream lake influences, as well as increased quality control in the sample handling. They found a significant relationship between DOC and UVR with very little scatter away from the trend line.

Streams on northern Vancouver Island, approximately north of the Tsitika River, are known to generally be tea-coloured, indicating naturally high levels of tannins and other organic compounds. Tsulquate River (Nahwitti Lowland Site) was the only site in this study that fell within this zone, which corresponds with the high DOC, UVR absorbance and SUVA values at this site. Newcastle Creek (Leeward Island Mountain Site), just south of this zone, had the second highest DOC concentration, UVR absorbance and median SUVA values of all study sites. This suggests that these north-easterly locations are more conducive to providing large amounts of coloured DOC for attenuation. The high degree of aromaticity of DOC is probably well maintained due to the fact that both of these sites have a large percentage of old forest but very little or no forest harvesting and agriculture. According to previous studies, forest harvesting and agricultural land uses can be detrimental to DOC quality (Buien *et al*., 2003; Findlay *et al*., 2001; Harding *et al.*, 1998; Piccolo *et al*., 2005; Rae *et al*. 2001b). It is unlikely that the Nahwitti Lowland or the northern part of the Leeward Island Mountain ecoregions will be subject to UVR absorbance at low levels during the March 1 to October 1 period. Thus, aquatic ecosystems in these zones are likely not in danger of excessive modifications as a result of UVR damage. However, with only one watershed studied in each of these ecoregions, more data is required to draw conclusions in this regard. More sample sites are necessary to support the trends that appear to be present in these regions of the Island.

Of the sites with moderate DOC and UVR attenuation levels (Nanaimo Lowland sites and Mercantile Creek in the Windward Island Mountain ecoregion), only Mercantile and Holland Creeks had median SUVA levels greater than 3 L/mg-M. Thus, these moderate-high SUVA sites likely have more terrestrially derived DOC and fulvic acid, even though they do not have very high DOC levels. Holland Creek has almost no old forest, but nearly 94% young forest, the result of extensive past forest harvesting. This may suggest that young forest beyond a certain age contributes positively to the amounts of coloured DOC. This needs to be further investigated using detailed dates of forest harvesting. Holland Creek also has no agriculture or urban impacts, and minimal recent logging, unlike the three other Nanaimo Lowland sites. This supports that anthropological impacts reduce DOC quality. Despite the fact that nearly half of the watershed for Mercantile Creek had been recently logged, the presence of an old forest buffer zone may literally buffer effects from forest harvesting at the sample site. The presence or absence of trees as a result of deforestation influences the slumping of hillslope soils into the near-stream areas and indirectly changes the amount of sunlight that reaches water within the watershed (Findlay *et al*. 2001). Mercantile Creek is also prone to landslides (Epps, per. com. 2006) and has some very recent logging, both factors that may increase DOC in the creek. It would be useful to perform an analysis of the fulvic acid, as well as the aromaticity content in the water samples, to determine if fulvic acid differences are in fact the cause for the difference in UVR attenuation levels.

The other waterbodies in the Nanaimo Lowlands (Tsolum, Englishman and Little Qualicum Rivers) had moderate DOC levels, but low to moderate SUVA values. This suggests that low amounts of coloured DOC are present on these rivers, and this is likely greatly affected by multiple anthropogenic land uses in the watersheds. Both the Tsolum and Englishman Rivers showed significant correlations between DOC and UVR attenuation. This may indicate that non-coloured DOC may have a more defined relationship to UVR attenuation than do the variations of coloured DOC. With only one year of data collection, it is difficult to speculate whether the Little Qualicum may also have shown similar relationship. Due to the implications that low UVR absorbance has on the health of aquatic ecosystems, watersheds with moderate to low DOC levels and heavy anthropogenic land use (like the Nanaimo Lowlands) are at risk during the spring and summer months and with future increases in UVR.

McKelvie Creek, San Juan River and China Creek, all in the Windward Island Mountains, had the three lowest median DOC levels in the study and UVR absorbance levels at or near MDL during the March 1 to October 1 period. McKelvie Creek is the only watershed within this area that had very little forest harvesting, yet DOC, UVR absorption and SUVA values were still only moderate-low. Thus, it appears as though this ecoregion may naturally produce little and probably non-coloured DOC. This may be supported by the fact that McKelvie Creek was one of the three waterbodies that showed a significant relationship between DOC and UVR attenuation. The other watersheds in this ecoregion have some of the highest percentages of recent logging in this study. As the primary anthropogenic land use in the ecoregion, this likely further contributes to the very poor UVR attenuation in these waterbodies. Noteably, the San Juan had moderate-high SUVA values. Like Mercantile Creek, discussed above, nearly half of the San Juan watershed has been recently logged. This implies that although DOC may naturally be poor here, recent logging may be temporarily increasing DOC quality. Due to the above factors, aquatic ecosystems within waterbodies in the Windward Island Mountains are at risk during the spring and summer months and with future increases in UVR.

Despite apparent influences of forest harvesting and other anthropogenic land uses observed in this dataset, there were no significant relationships between any anthropogenic land uses and UVR attenuation or DOC levels. In regards to forest harvesting, this was probably due to the inability, considering the scope of this project, to delve into topography, slope and precise dates of logging. These factors potentially influence amount and quality of DOC reaching waterbodies (Collier and Bowman 2003). Considering agriculture, it is most likely due to the fact that agriculture comprised only 1.4% of the total land uses for all sites. According to at least two studies (Findlay *et al*., 2001; Rae *et al*. 2001b) the kind and quantity of vegetation, in particular the amount of forest, will directly affect the DOC quality through its exposure to photodegradation before it enters the waterbody. Also, Buien *et al*. (2003) showed that all treatments of fertilization for agricultural purposes decrease the fulvic acid content, while Harding *et al*. (1998) showed that past land-use activity, particularly agriculture, may result in long-term modifications to and reductions in aquatic diversity. Further research should go into examining more watersheds dominated by forest harvesting and agriculture. Forest harvesting data should include the age of the cut blocks to account for the fluxes of DOC into the system after the initial logging and recovery time.

Amongst all land uses considered, only one (open freshwater) was significantly ($p<0.05$) related to attenuation of UVR, but became nonsignificant with removal of the Tsulquate data. Thus, it is possible that the data is affected by the high percentage of open freshwater, DOC content and the UVR attenuation of the Tsulquate River. More sites are needed in the Nahwitti Lowland ecoregion, or in watersheds that contain lakes and open water, to be able to confirm or reject these findings. Keeping in mind that the order of the stream and presence of standing water above or at the sample may effect the relationship between DOC and UVR, as apparent when comparing this data to Bothwell *et al*. (2002), it is also important to limit studies to similar stream orders and lake influences (or lack of).

Results for a given stream may show a very low absorbance value, indicating that it would be vulnerable to UVR; however, in reality there may be other factors on site that offer protection from UVR, such as a dense canopy, deep water, or many large woody debris structures. It would be useful to perform in-stream experiments to determine the UVR sensitivity of entire streams or reaches. This would help to take into account external factors in the stream environment. A profiling UV radiometer could be used to determine the amount of UV reaching the stream as well as record temperature and depth at each sample site. Data could be used to calculate an at-risk quotient that could be applied to streams or watersheds.

Conclusions

Vancouver Island DOC and UVR absorbance data provided valuable information regarding the basic differences in susceptibility of aquatic ecosystems in some of the Island's ecoregions. As a result of naturally occurring high quality/large amounts of DOC, aquatic ecosystems in the Nahwitti Lowland and the Leeward Island Mountains ecoregions are likely not in danger of excessive modifications as a result of UVR damage. Despite their apparent non-coloured DOC and poor UVR attenuation, aquatic ecosystems in Nanaimo Lowland watersheds are considered to be susceptible to spring and summer UVR levels, especially if the watershed has several anthropological land uses. Windward Island Mountain sites appear to have naturally low levels and/or quality of DOC. Thus, aquatic ecosystems in this zone are at risk of excessive exposure to UVR in the spring and summer months. More sites should be considered within individual ecoregions, especially the Nahwitti Lowland and Leeward Island Mountains ecoregions, to further support these observations.

As expected based on other studies, DOC and UVR attenuation data showed a significant correlation ($p<0.05$), while seasonal peaks in these parameters corresponded to peak rainfall periods. Reviewed by watershed, the significant relationship between DOC and UVR was limited to only some of the watersheds with the lowest SUVA values and thus, the least amount of coloured-DOC. Though it was not clear in this dataset, presence of lakes above or at the sample site may also influence the relationship; thus, future studies should be limited to particular stream orders or lake influences.

Despite apparent influence from various anthropogenic land uses, significant relationships between specific land uses and DOC or UVR attenuation were observed only for open freshwater (a non-anthropological land use). This relationship was questionable. Further investigation regarding specific land uses should focus on several watersheds with similar land uses. Agriculture and forest harvesting should be the priority land uses investigated. This study does suggest that recent logging may increase DOC quality temporarily. In addition, it suggests that a forest harvesting buffer area contributes to coloured DOC. Land use data should include details and dates of logging.

Finally, some areas of interest were identified that should be considered in future studies. Additional sampling should be done to determine the fulvic acid, aromaticity content and degradation history of the DOC in streams. This will help to predict the amount of coloured DOC in terms of UVR protection. Future studies should also incorporate sampling of in-stream parameters and site characteristics to determine the vulnerability of the stream and its ability for protection from impacts of UVR.

River discharge data should be compiled and included in future studies relating to DOC and UVR relationships to confirm effects of precipitation on DOC levels. Water Survey of Canada stations do exist at the Englishman and Tsolum Rivers and at Mercantile Creek.

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Appendix 1 – DOC concentration and UVR absorbance figures for each study site, 2002-05.

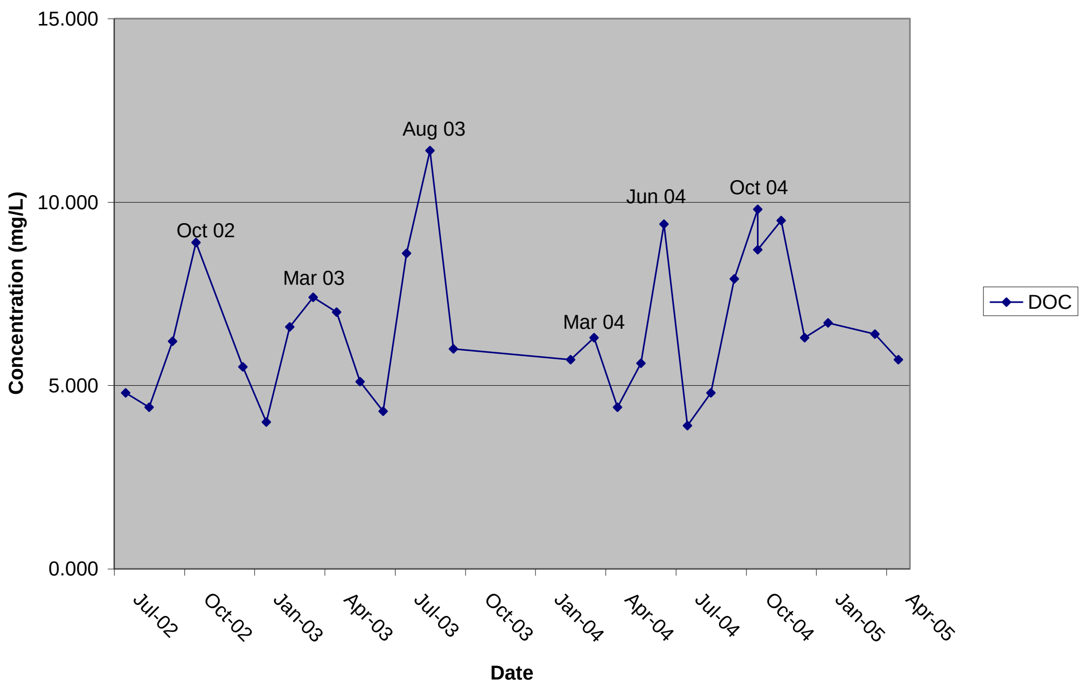

Figure 11. Tsulquate River DOC concentration, in mg/L, sampled monthly 2002-05.

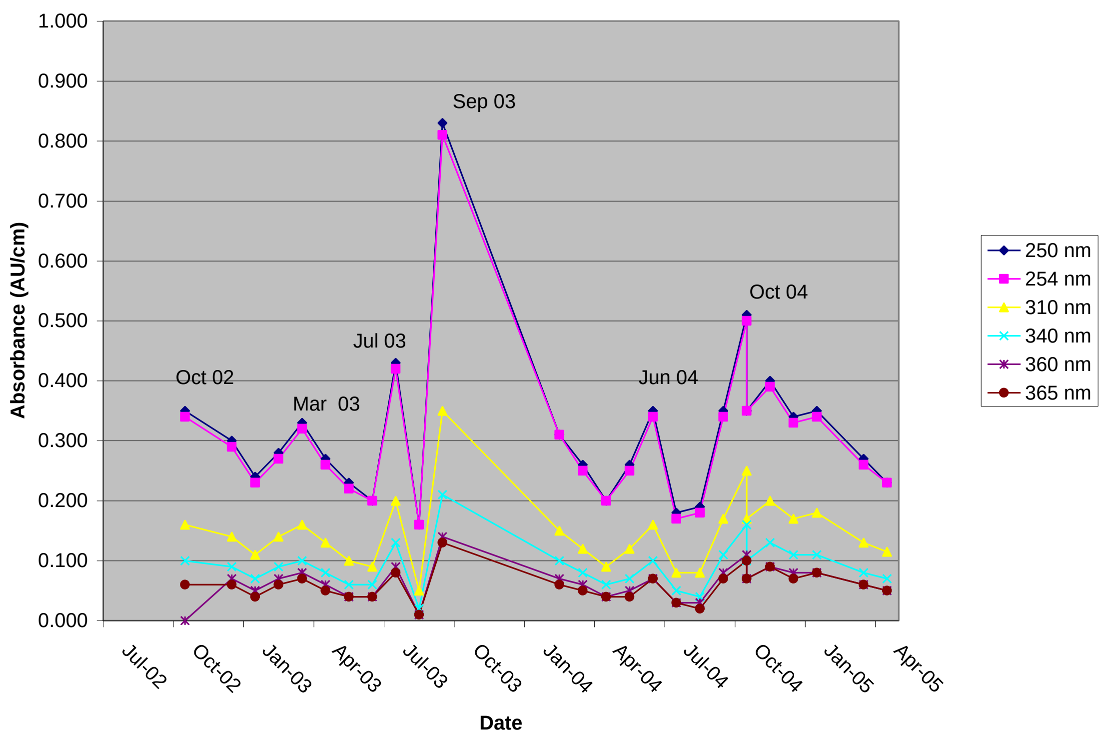

Figure 12. Tsulquate River UVR absorbance, in AU/cm, sampled monthly 2002-05.

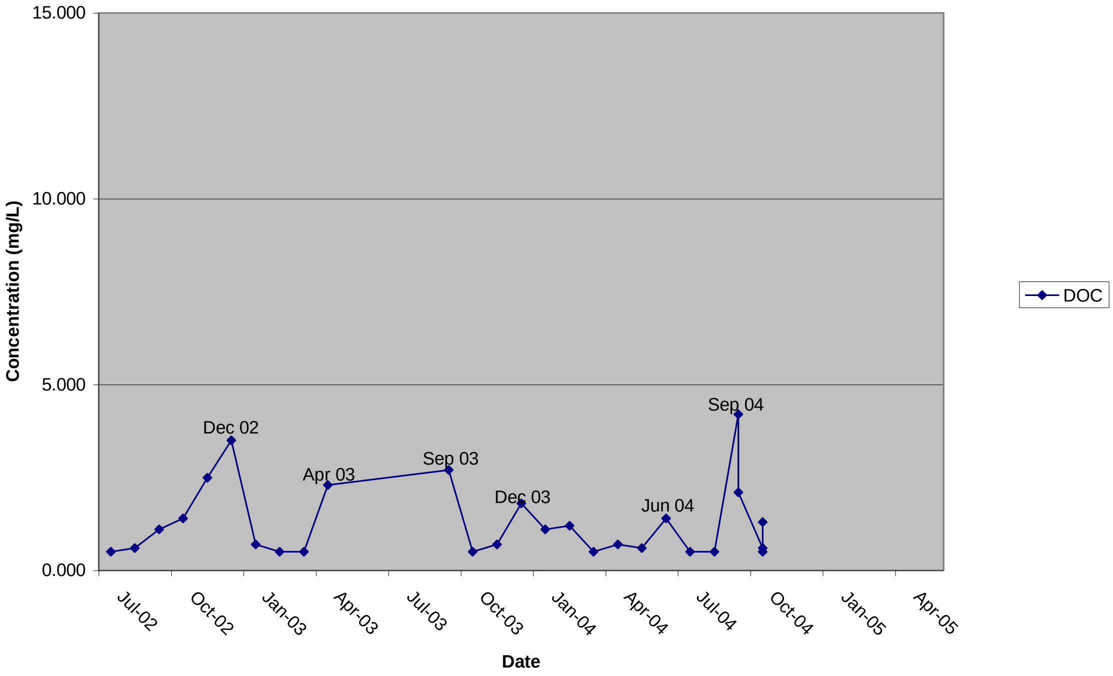

Figure 13. McKelvie Creek DOC concentration, in mg/L, sampled monthly 2002-05.

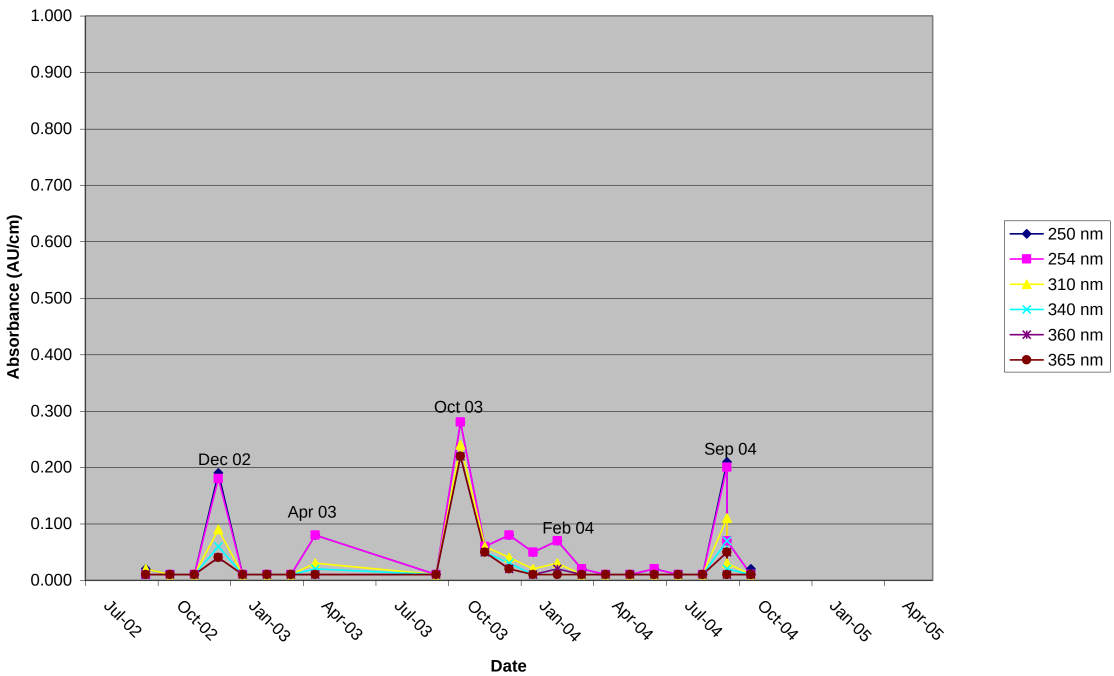

Figure 14. McKelvie Creek UVR absorbance, in AU/cm, sampled monthly 2002-05.

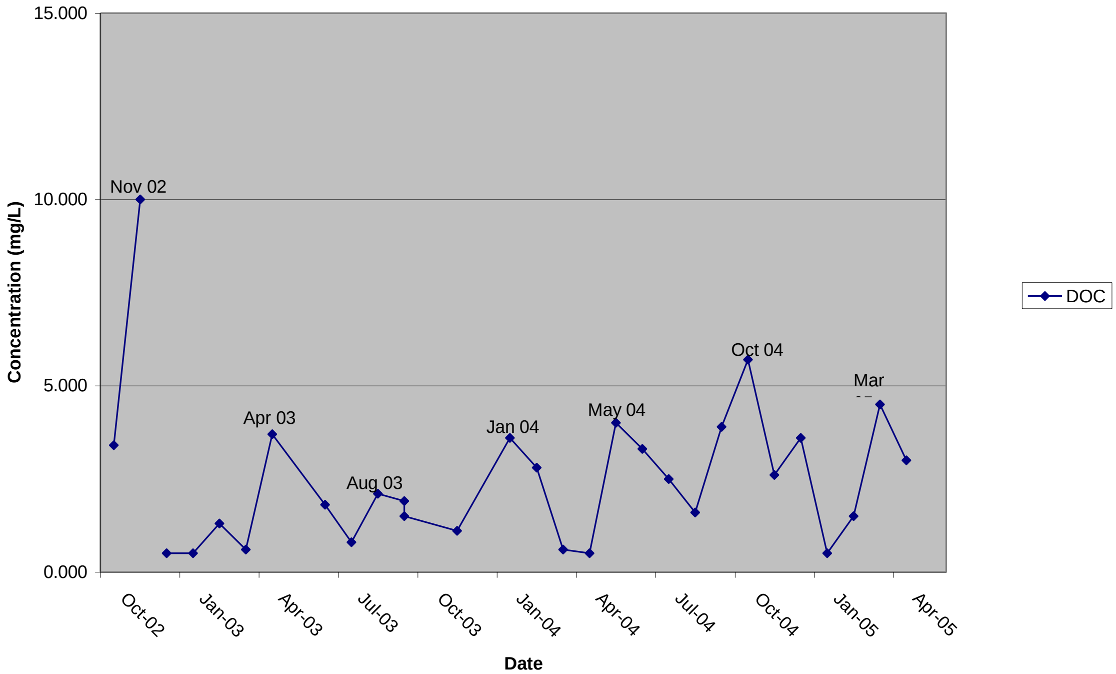

Figure 15. Mercantile Creek DOC concentration, in mg/L, sampled monthly 2002-05.

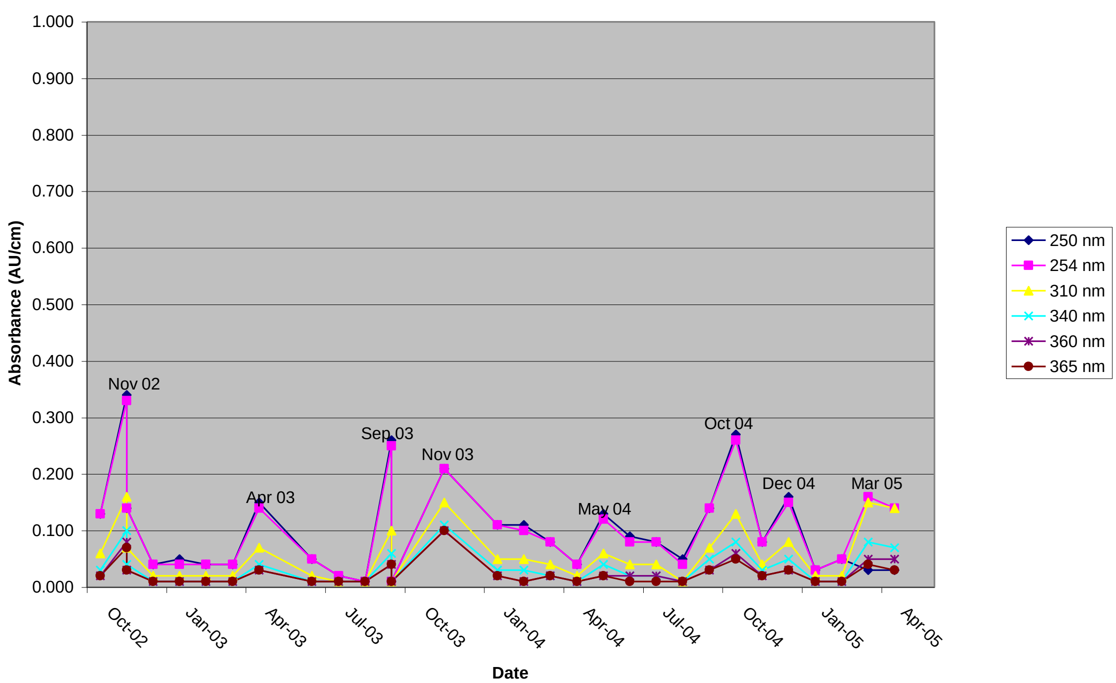

Figure 16. Mercantile Creek UVR absorbance, in AU/cm, sampled monthly 2002-05.

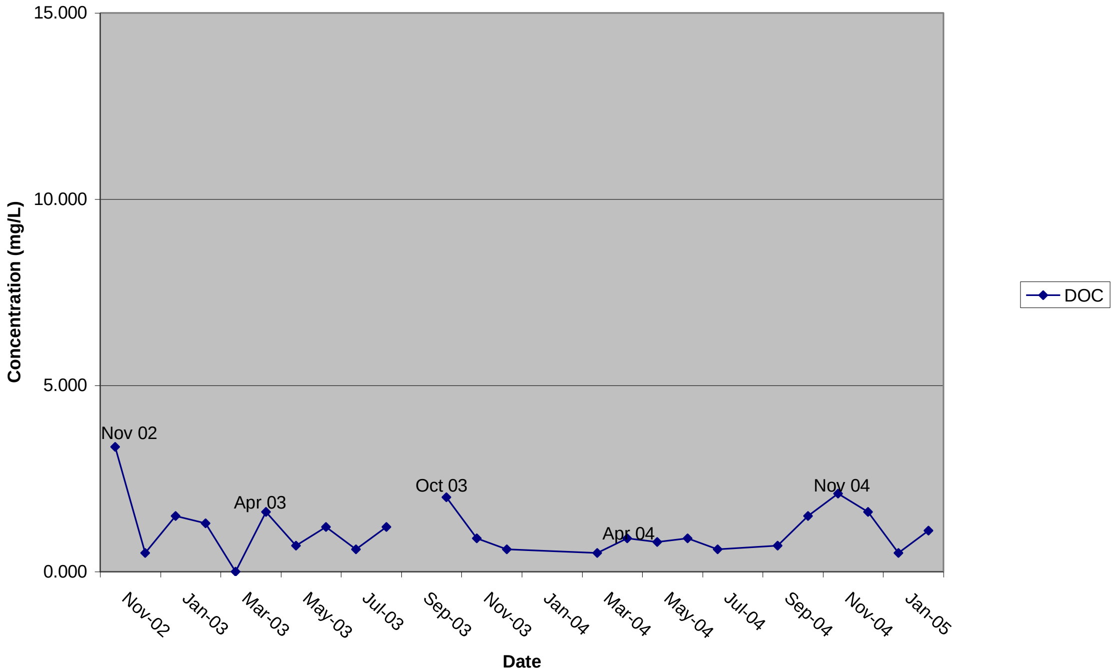

Figure 17. China Creek DOC concentration, in mg/L, sampled monthly 2002-05.

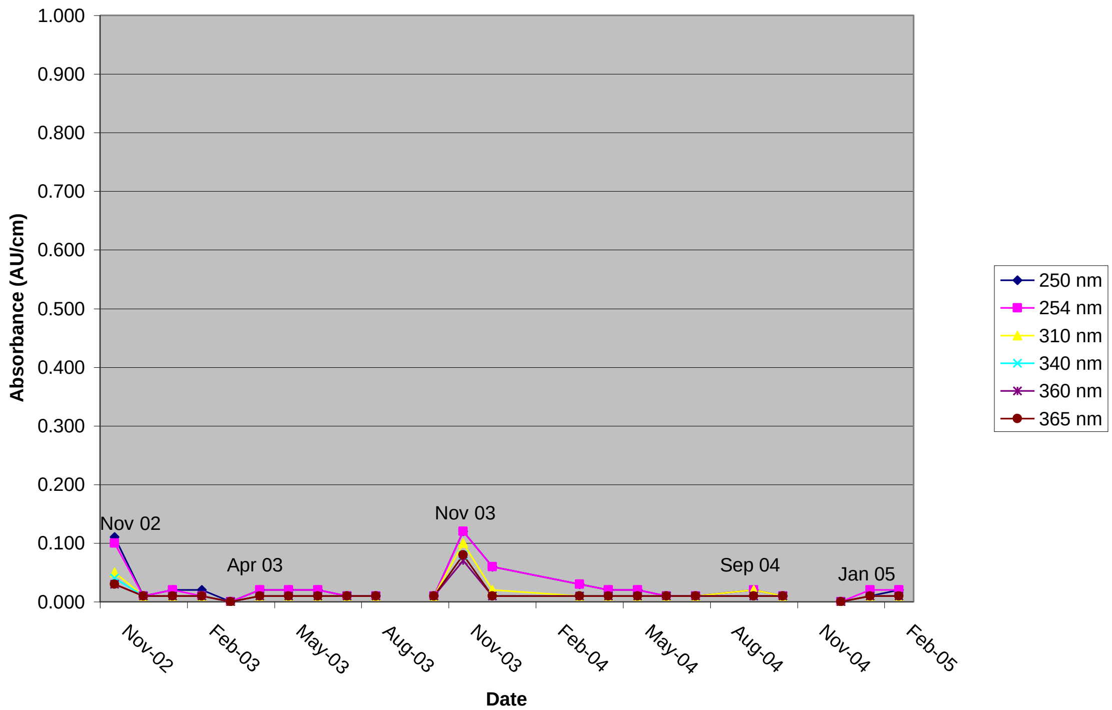

Figure 18. China Creek UVR absorbance, in AU/cm, sampled monthly 2002-05.

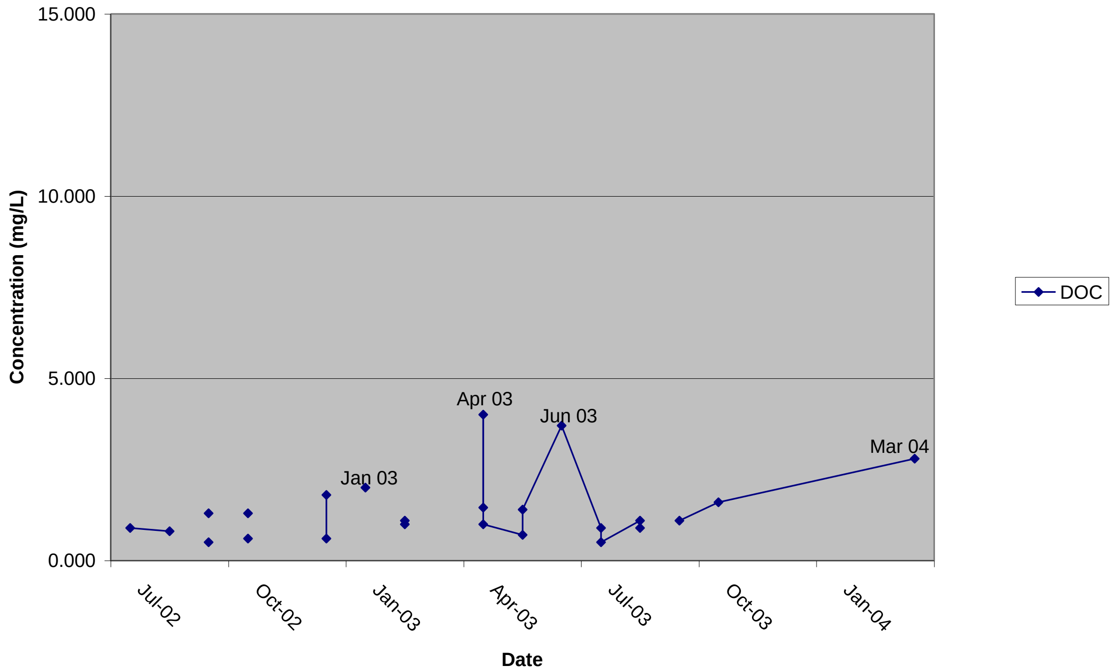

Figure 19. San Juan River DOC concentration, in mg/L, sampled monthly 2002-04.

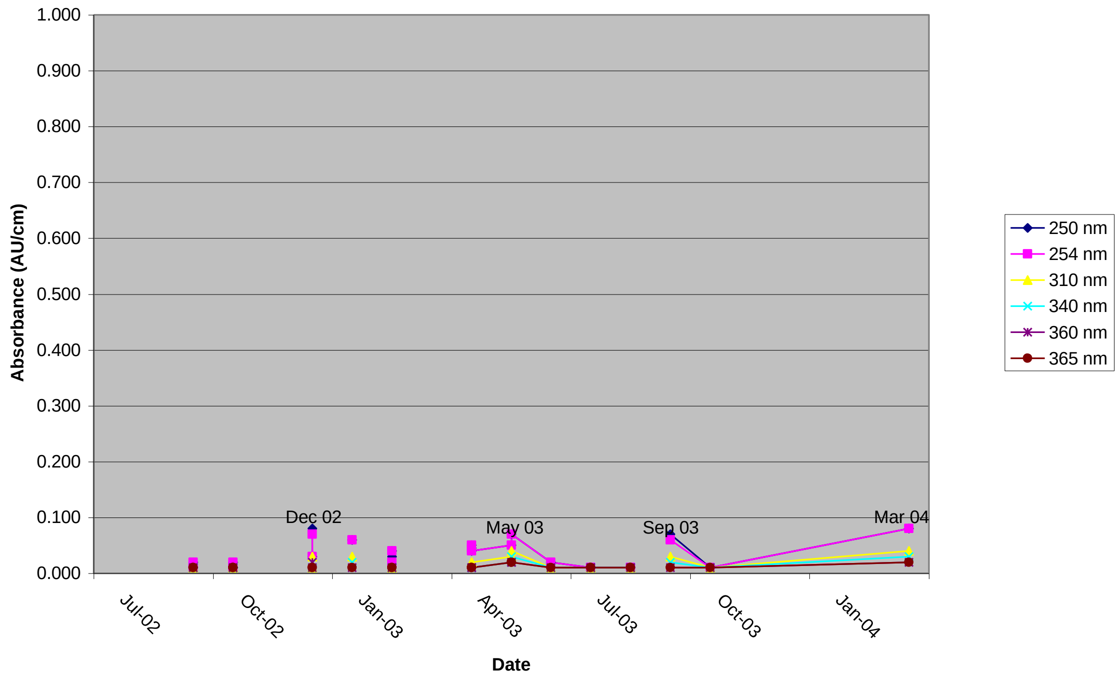

Figure 20. San Juan River UVR absorbance, in AU/cm, sampled monthly 2002-04.

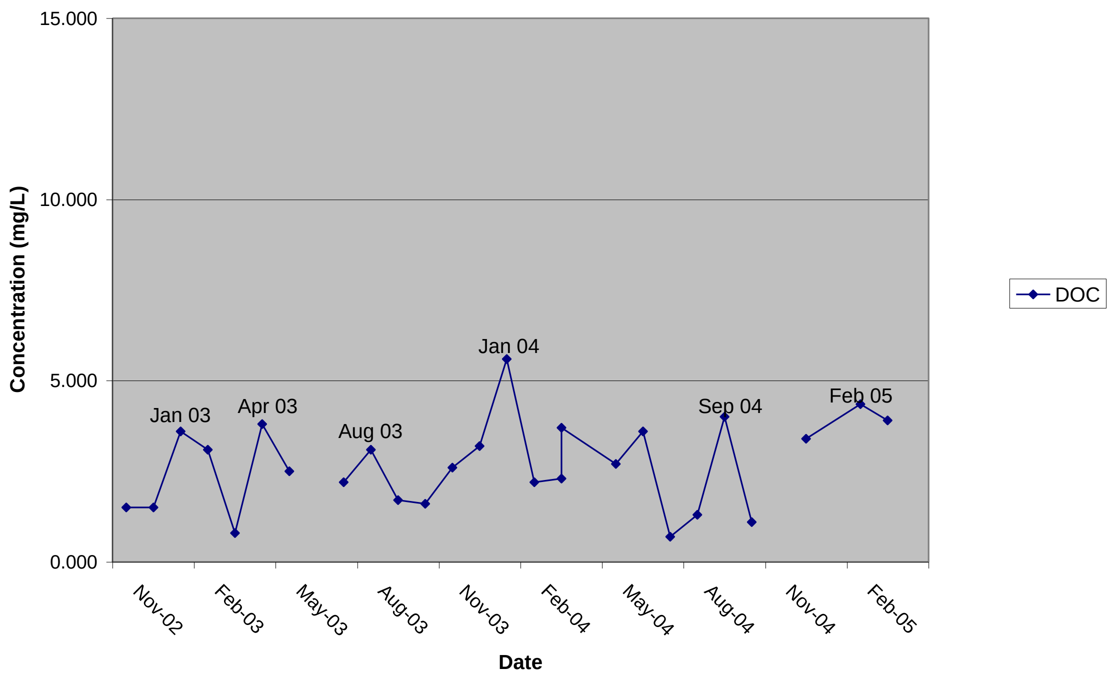

Figure 21. Newcastle Creek DOC concentration, in mg/L, sampled monthly 2002-05.

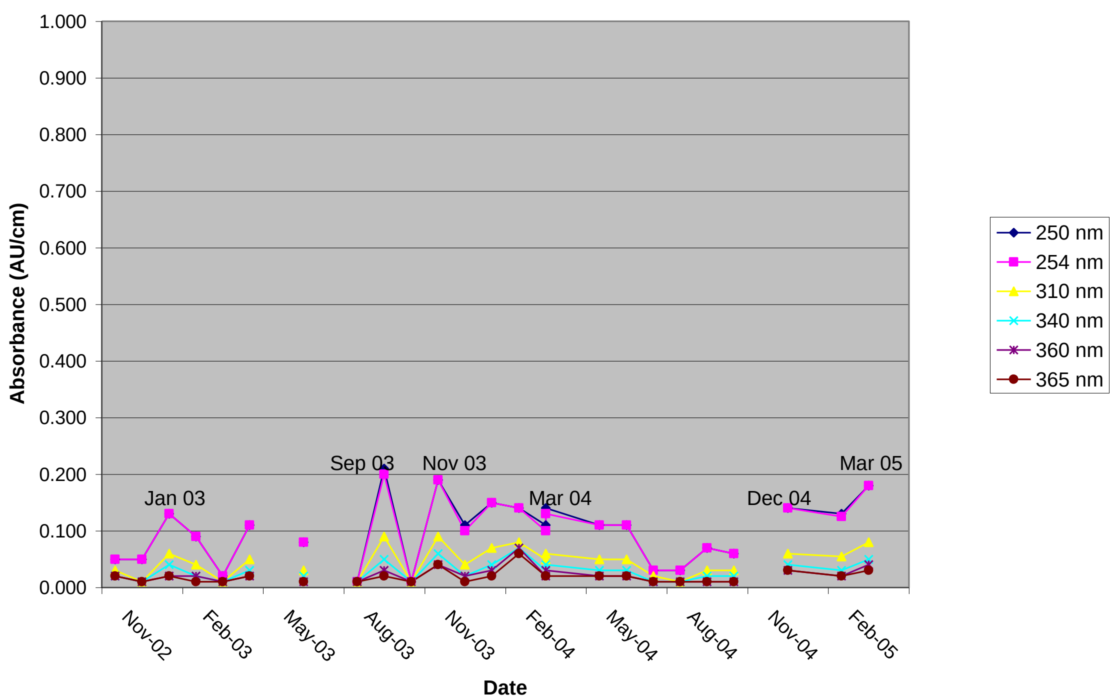

Figure 22. Newcastle Creek UVR absorbance, in AU/cm, sampled monthly 2002-05.

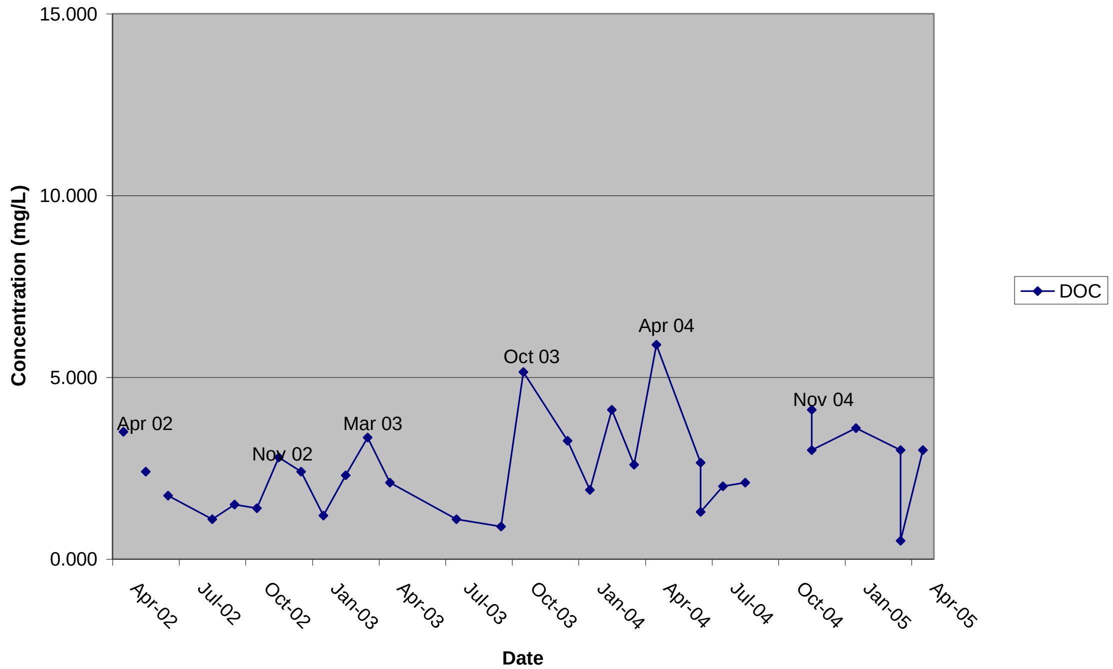

Figure 23. Tsolum River DOC concentration, in mg/L, sampled monthly 2002-05.

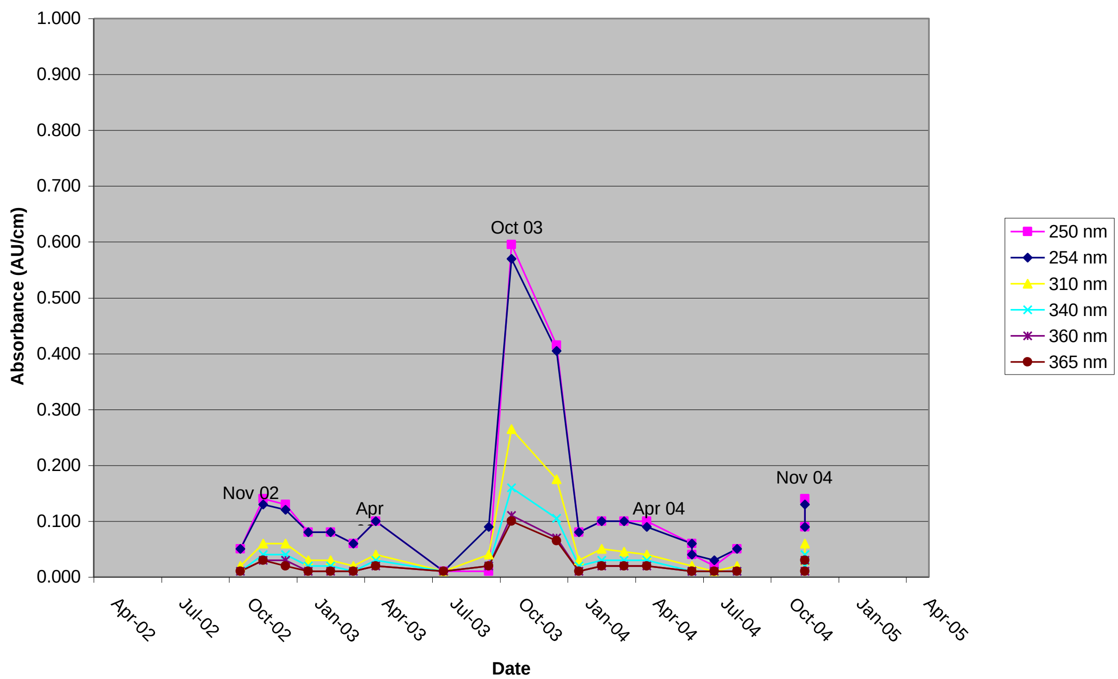

Figure 24. Tsolum River UVR absorbance, in AU/cm, sampled monthly 2002-05.

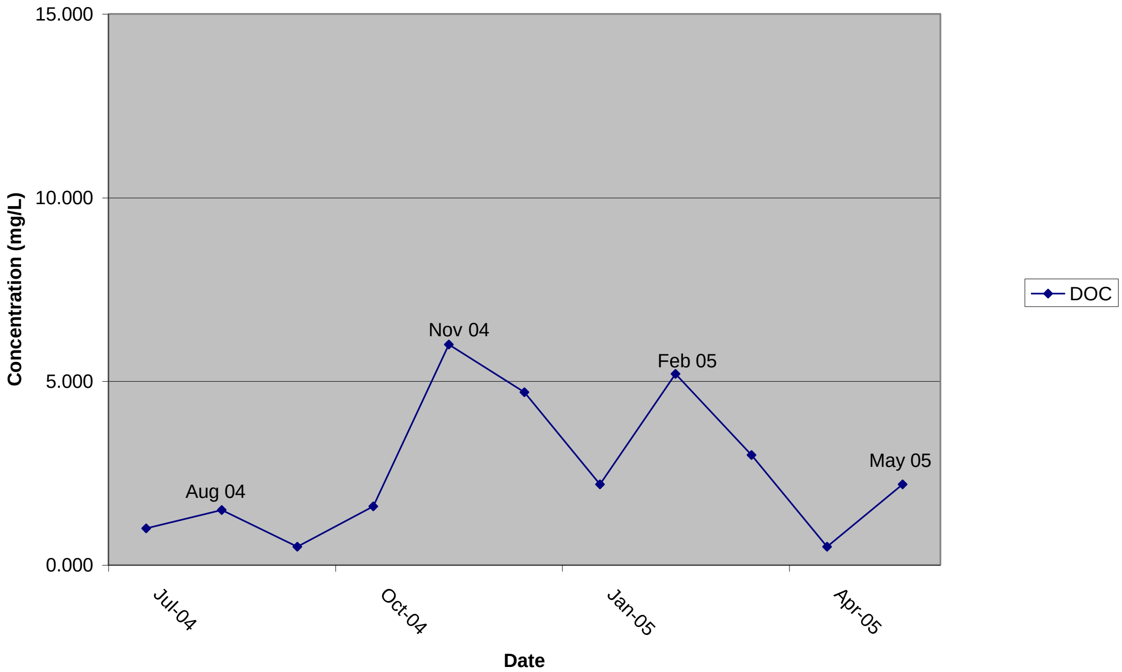

Figure 25. Little Qualicum River DOC concentration, in mg/L, sampled monthly 2004-05.

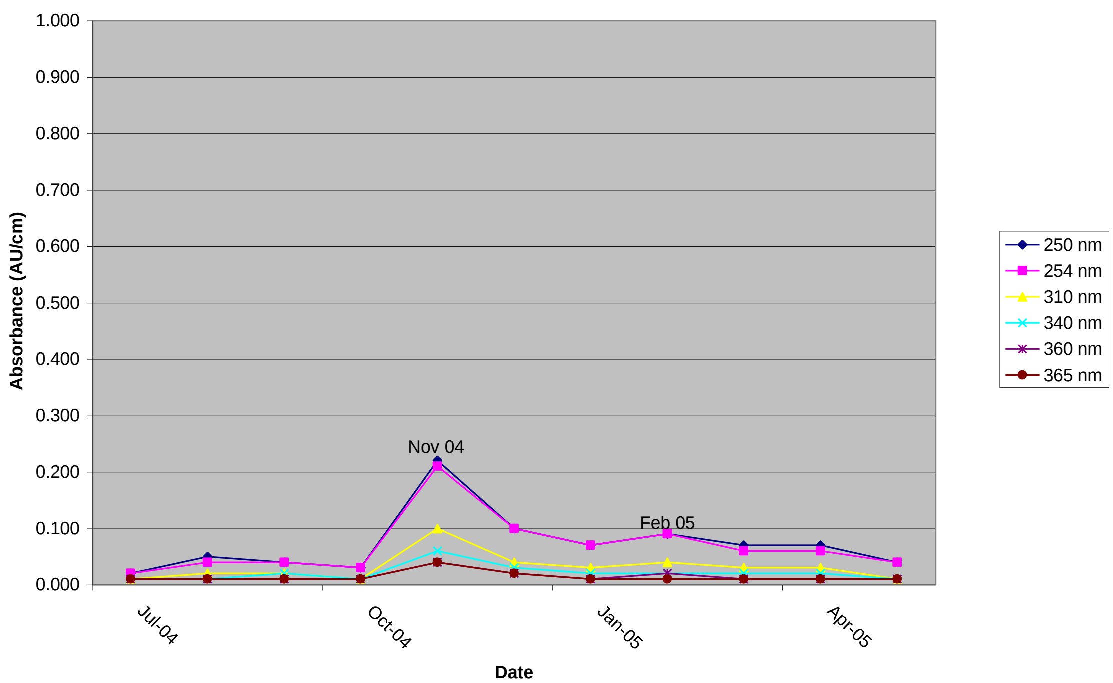

Figure 26. Little Qualicum River UVR absorbance, in AU/cm, sampled monthly 2004-05.

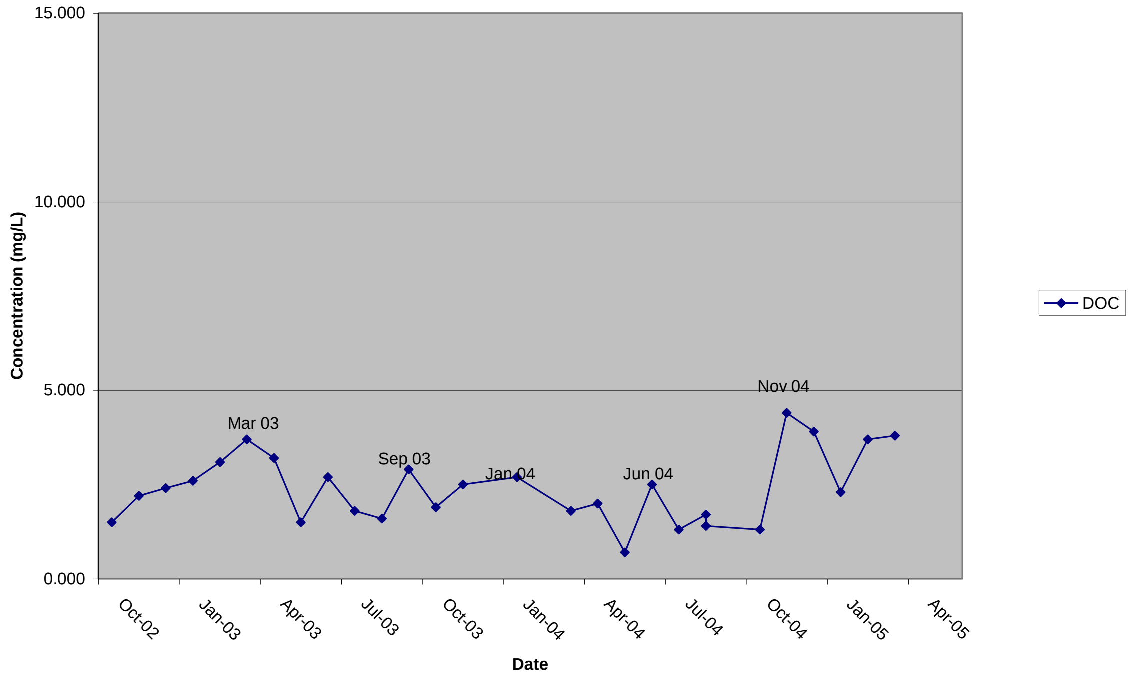

Figure 27. Englishman River DOC concentration, in mg/L, sampled monthly 2002-05.

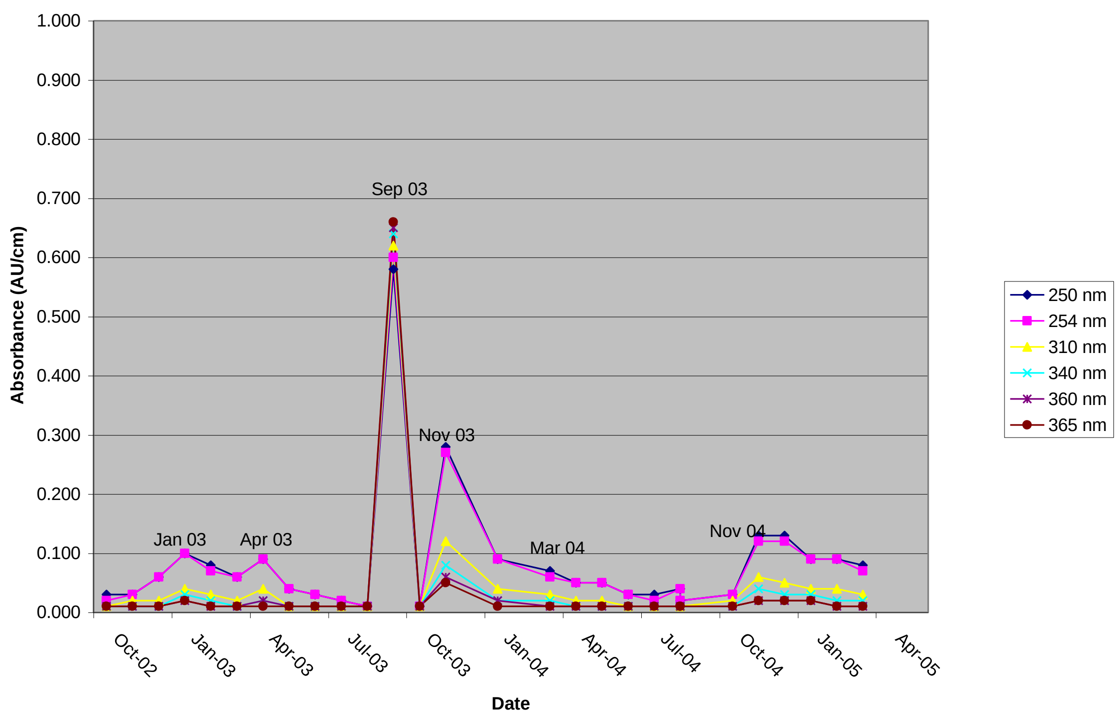

Figure 28. Englishman River UVR absorbance, in AU/cm, sampled monthly 2002-05.

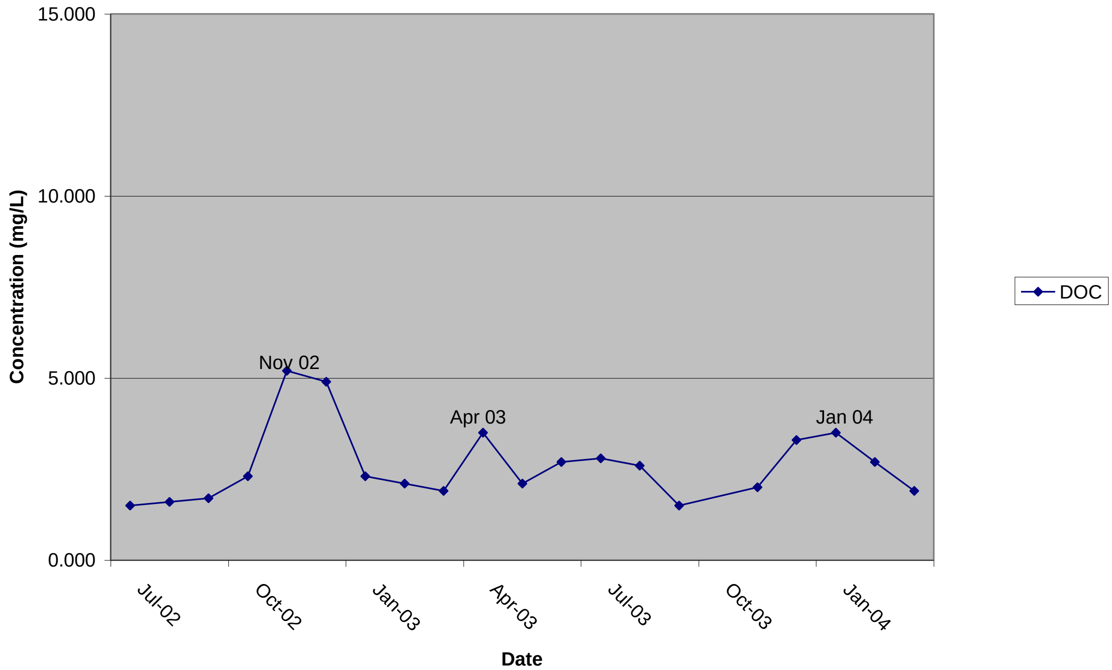

Figure 29. Holland Creek DOC concentration, in mg/L, sampled monthly 2002-05.

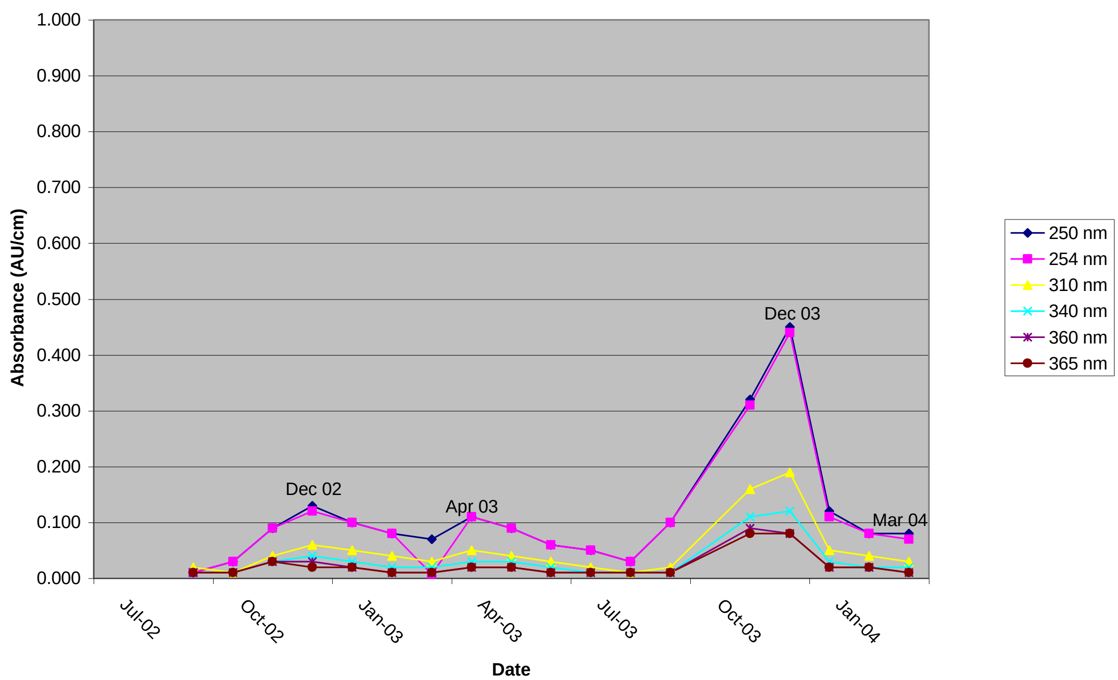

Figure 30. Holland Creek UVR absorbance, in AU/cm, sampled monthly 2002-05.

Appendix 2 – DOC concentration and UVR absorbance data tables for each study site, 2002-05.

Table 4. Summary of 2002-05 Tsulquate River DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	**DOC**	**UV**					
		250 nm	**254 nm**	**310 nm**	**340 nm**	**360 nm**	**365 nm**
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
9-Jul-02	4.800						
1-Aug-02	4.400						
3-Sep-02	6.200						
8-Oct-02	8.900	0.350	0.340	0.160	0.100	0.000	0.060
8-Jan-03	4.000	0.240	0.230	0.110	0.070	0.050	0.040
17-Dec-02	5.500	0.300	0.290	0.140	0.090	0.070	0.060
11-Feb-03	6.600	0.280	0.270	0.140	0.090	0.070	0.060
4-Mar-03	7.400	0.330	0.320	0.160	0.100	0.080	0.070
9-Apr-03	7.000	0.270	0.260	0.130	0.080	0.060	0.050
6-May-03	5.100	0.230	0.220	0.100	0.060	0.040	0.040
10-Jun-03	4.300	0.200	0.200	0.090	0.060	0.040	0.040
15-Jul-03	8.600	0.430	0.420	0.200	0.130	0.090	0.080
6-Aug-03	11.400	0.160	0.160	0.050	0.020	0.010	0.010
2-Sep-03	6.000	0.830	0.810	0.350	0.210	0.140	0.130
4-Feb-04	5.700	0.310	0.310	0.150	0.100	0.070	0.060
9-Mar-04	6.300	0.260	0.250	0.120	0.080	0.060	0.050
7-Apr-04	4.400	0.200	0.200	0.090	0.060	0.040	0.040
6-May-04	5.600	0.260	0.250	0.120	0.070	0.050	0.040
2-Jun-04	9.400	0.350	0.340	0.160	0.100	0.070	0.070
6-Jul-04	3.900	0.180	0.170	0.080	0.050	0.030	0.030
4-Aug-04	4.800	0.190	0.180	0.080	0.040	0.030	0.020
1-Sep-04	7.900	0.350	0.340	0.170	0.110	0.080	0.070
6-Oct-04	9.800	0.510	0.500	0.250	0.160	0.110	0.100
13-Oct-04	8.700	0.350	0.350	0.170	0.100	0.070	0.070
2-Nov-04	9.500	0.400	0.390	0.200	0.130	0.090	0.090
14-Dec-04	6.300	0.340	0.330	0.170	0.110	0.080	0.070
18-Jan-05	6.700	0.350	0.340	0.180	0.110	0.080	0.080
10-Mar-05	6.400	0.270	0.260	0.130	0.080	0.060	0.060
5-Apr-05	5.700	0.230	0.230	0.115	0.070	0.050	0.050
Summary statistics using data from March 1st to October 1st only							
Min	3.900	0.160	0.160	0.050	0.020	0.010	0.010
Median	6.000	0.260	0.250	0.120	0.075	0.055	0.050

Table 5. Summary of 2002-04 McKelvie Creek DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	**DOC**	**UV**					
		250 nm	**254 nm**	**310 nm**	**340 nm**	**360 nm**	**365 nm**
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
9-Jul-02	0.500						
6-Aug-02	0.600						
3-Sep-02	1.100	0.020	0.010	0.020	0.010	0.010	0.010
8-Oct-02	1.400	0.010	0.010	0.010	0.010	0.010	0.010
5-Nov-02	2.500	0.010	0.010	0.010	0.010	0.010	0.010
10-Dec-02	3.500	0.190	0.180	0.090	0.060	0.040	0.040
7-Jan-03	0.700	0.010	0.010	0.010	0.010	0.010	0.010
4-Feb-03	0.500	0.010	0.010	0.010	0.010	0.010	0.010
4-Mar-03	0.500	0.010	0.010	0.010	0.010	0.010	0.010
8-Apr-03	2.300	0.080	0.080	0.030	0.020	0.010	0.010
2-Sep-03	2.700	0.010	0.010	0.010	0.010	0.010	0.010
14-Oct-03	0.500	0.280	0.280	0.240	0.220	0.220	0.220
4-Nov-03	0.700	0.060	0.060	0.060	0.050	0.050	0.050
2-Dec-03	1.800	0.080	0.080	0.040	0.030	0.020	0.020
12-Jan-04	1.100	0.050	0.050	0.020	0.010	0.010	0.010
17-Feb-04	1.200	0.070	0.070	0.030	0.020	0.020	0.010
23-Mar-04	0.500	0.020	0.020	0.010	0.010	0.010	0.010
21-Apr-04	0.700	0.010	0.010	0.010	0.010	0.010	0.010
18-May-04	0.600	0.010	0.010	0.010	0.010	0.010	0.010
15-Jun-04	1.400	0.020	0.020	0.010	0.010	0.010	0.010
13-Jul-04	0.500	0.010	0.010	0.010	0.010	0.010	0.010
16-Aug-04	0.500	0.010	0.010	0.010	0.010	0.010	0.010
8-Sep-04	4.200	0.210	0.200	0.110	0.070	0.050	0.050
22-Sep-04	2.100	0.070	0.070	0.030	0.020	0.010	0.010
4-Oct-04	0.600	0.010	0.010	0.010	0.010	0.010	0.010
19-Oct-04	0.500	0.010	0.010	0.010	0.010	0.010	0.010
25-Oct-04	1.300	0.020	0.010	0.010	0.010	0.010	0.010
Summary statistics using data from March 1st to October 1st only							
Min	0.500	0.010	0.010	0.010	0.010	0.010	0.010
Median	0.650	0.015	0.010	0.010	0.010	0.010	0.010

Table 6. Summary of 2002-05 Mercantile Creek DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	DOC	UV					
		250 nm	254 nm	310 nm	340 nm	360 nm	365 nm
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
3-Oct-02	3.400	0.130	0.130	0.060	0.030	0.020	0.020
06/11/2002	10.000	0.340	0.330	0.160	0.100	0.080	0.070
20-Nov-02		0.140	0.140	0.070	0.040	0.030	0.030
4-Dec-02	0.500	0.040	0.040	0.020	0.010	0.010	0.010
8-Jan-03	0.500	0.050	0.040	0.020	0.010	0.010	0.010
5-Feb-03	1.300	0.040	0.040	0.020	0.010	0.010	0.010
5-Mar-03	0.600	0.040	0.040	0.020	0.010	0.010	0.010
2-Apr-03	3.700	0.150	0.140	0.070	0.040	0.030	0.030
4-Jun-03	1.800	0.050	0.050	0.020	0.010	0.010	0.010
9-Jul-03	0.800	0.020	0.020	0.010	0.010	0.010	0.010
12-Aug-03	2.100	0.010	0.010	0.010	0.010	0.010	0.010
9-Sep-03	1.900	0.260	0.250	0.100	0.060	0.040	0.040
30-Sep-03	1.500	0.010	0.010	0.010	0.010	0.010	0.010
10-Nov-03	1.100	0.210	0.210	0.150	0.110	0.100	0.100
19-Jan-04	3.600	0.110	0.110	0.050	0.030	0.020	0.020
4-Feb-04	2.800	0.110	0.100	0.050	0.030	0.010	0.010
16-Mar-04	0.600	0.080	0.080	0.040	0.020	0.020	0.020
14-Apr-04	0.500	0.040	0.040	0.020	0.010	0.010	0.010
5-May-04	4.000	0.130	0.120	0.060	0.040	0.020	0.020
1-Jun-04	3.300	0.090	0.080	0.040	0.020	0.020	0.010
7-Jul-04	2.500	0.080	0.080	0.040	0.020	0.020	0.010
4-Aug-04	1.600	0.050	0.040	0.010	0.010	0.010	0.010
1-Sep-04	3.900	0.140	0.140	0.070	0.050	0.030	0.030
6-Oct-04	5.700	0.270	0.260	0.130	0.080	0.060	0.050
3-Nov-04	2.600	0.080	0.080	0.040	0.030	0.020	0.020
8-Dec-04	3.600	0.160	0.150	0.080	0.050	0.030	0.030
10-Jan-05	0.500	0.030	0.030	0.020	0.010	0.010	0.010
8-Feb-05	1.500	0.050	0.050	0.020	0.010	0.010	0.010
7-Mar-05	4.500	0.030	0.160	0.150	0.080	0.050	0.040
13-Apr-05	3.000	0.030	0.140	0.140	0.070	0.050	0.030
Summary statistics using data from March 1st to October 1st only							
Min	0.500	0.010	0.010	0.010	0.010	0.010	0.010
Median	2.000	0.050	0.080	0.040	0.020	0.020	0.010

Table 7. Summary of 2002-05 China Creek DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	**DOC**	**UV**					
		250 nm	**254 nm**	**310 nm**	**340 nm**	**360 nm**	**365 nm**
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
12-Nov-02	3.350	0.110	0.100	0.050	0.040	0.030	0.030
2-Dec-02	0.500	0.010	0.010	0.010	0.010	0.010	0.010
6-Jan-03	1.500	0.020	0.020	0.010	0.010	0.010	0.010
4-Feb-03	1.300	0.020	0.010	0.010	0.010	0.010	0.010
3-Mar-03							
1-Apr-03	1.600	0.020	0.020	0.010	0.010	0.010	0.010
1-May-03	0.700	0.020	0.020	0.010	0.010	0.010	0.010
3-Jun-03	1.200	0.020	0.020	0.010	0.010	0.010	0.010
23-Jul-03	0.600	0.010	0.010	0.010	0.010	0.010	0.010
5-Aug-03	1.200	0.010	0.010	0.010	0.010	0.010	0.010
3-Sep-03							
2-Oct-03	2.000	0.010	0.010	0.010	0.010	0.010	0.010
3-Nov-03	0.900	0.120	0.120	0.100	0.080	0.070	0.080
1-Dec-03	0.600	0.060	0.060	0.020	0.010	0.010	0.010
18-Mar-04	0.500	0.030	0.030	0.010	0.010	0.010	0.010
1-Apr-04	0.900	0.020	0.020	0.010	0.010	0.010	0.010
4-May-04	0.800	0.020	0.020	0.010	0.010	0.010	0.010
2-Jun-04	0.900	0.010	0.010	0.010	0.010	0.010	0.010
5-Jul-04	0.600	0.010	0.010	0.010	0.010	0.010	0.010
16-Sep-04	0.700	0.020	0.020	0.020	0.010	0.010	0.010
4-Oct-04	1.500	0.010	0.010	0.010	0.010	0.010	0.010
2-Nov-04	2.100						
2-Dec-04	1.600						
6-Jan-05	0.500	0.010	0.020	0.010	0.010	0.010	0.010
2-Feb-05	1.100	0.020	0.020	0.010	0.010	0.010	0.010
Summary statistics using data from March 1st to October 1st only							
Min	0.500	0.010	0.010	0.010	0.010	0.010	0.010
Median	0.800	0.020	0.020	0.010	0.010	0.010	0.010

Table 8. Summary of 2002-04 San Juan River DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	DOC	UV					
		250 nm	254 nm	310 nm	340 nm	360 nm	365 nm
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
30-Jul-02	0.900						
13-Aug-02	0.800						
21-Aug-02							
28-Aug-02							
4-Sep-02	0.500	0.010	0.010	0.010	0.010	0.010	0.010
8-Sep-02							
17-Sep-02	1.300	0.020	0.020	0.010	0.010	0.010	0.010
24-Sep-02							
9-Oct-02	1.300	0.010	0.010	0.010	0.010	0.010	0.010
23-Oct-02		0.020	0.020	0.010	0.010	0.010	0.010
29-Oct-02	0.600	0.010	0.010	0.010	0.010	0.010	0.010
6-Nov-02							
20-Nov-02							
4-Dec-02	0.600	0.030	0.030	0.010	0.010	0.010	0.010
18-Dec-02	1.800	0.080	0.070	0.030	0.020	0.020	0.010
30-Dec-02							
15-Jan-03	2.000	0.060	0.060	0.030	0.020	0.010	0.010
29-Jan-03							
13-Feb-03	1.100	0.030	0.020	0.010	0.010	0.010	0.010
26-Feb-03	1.000	0.040	0.040	0.010	0.010	0.010	0.010
12-Mar-03							
26-Mar-03							
3-Apr-03	1.450	0.045	0.045	0.020	0.010	0.010	0.010
15-Apr-03	4.000	0.050	0.050	0.020	0.010	0.010	0.010
29-Apr-03	1.000	0.040	0.040	0.020	0.010	0.010	0.010
14-May-03	0.700	0.050	0.050	0.030	0.020	0.020	0.020
28-May-03	1.400	0.070	0.070	0.040	0.030	0.020	0.020
19-Jun-03	3.700	0.020	0.020	0.010	0.010	0.010	0.010
10-Jul-03	0.900	0.010	0.010	0.010	0.010	0.010	0.010
24-Jul-03	0.500	0.010	0.010	0.010	0.010	0.010	0.010
6-Aug-03	1.100	0.010	0.010	0.010	0.010	0.010	0.010
27-Aug-03	0.900	0.010	0.010	0.010	0.010	0.010	0.010
10-Sep-03							
17-Sep-03	1.100	0.070	0.060	0.030	0.020	0.010	0.010
8-Oct-03	1.600	0.010	0.010	0.010	0.010	0.010	0.010
9-Mar-04	2.800	0.080	0.080	0.040	0.030	0.020	0.020
Summary statistics using data from March 1st to October 1st only							
Min	0.500	0.010	0.010	0.010	0.010	0.010	0.010
Median	1.050	0.030	0.030	0.015	0.010	0.010	0.010

Table 9. Summary of 2002-05 Newcastle Creek DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	DOC	UV					
		250 nm	254 nm	310 nm	340 nm	360 nm	365 nm
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
4-Nov-02	1.500	0.050	0.050	0.030	0.020	0.020	0.020
2-Dec-02	1.500	0.050	0.050	0.010	0.010	0.010	0.010
6-Jan-03	3.600	0.130	0.130	0.060	0.040	0.020	0.020
1-Feb-03	3.100	0.090	0.090	0.040	0.020	0.020	0.010
5-Mar-03	0.800	0.020	0.020	0.010	0.010	0.010	0.010
1-Apr-03	3.800	0.110	0.110	0.050	0.030	0.020	0.020
6-May-03	2.500						
4-Jun-03		0.080	0.080	0.030	0.020	0.010	0.010
7-Jul-03	2.200						
5-Aug-03	3.100	0.010	0.010	0.010	0.010	0.010	0.010
3-Sep-03	1.700	0.210	0.200	0.090	0.050	0.030	0.020
1-Oct-03	1.600	0.010	0.010	0.010	0.010	0.010	0.010
4-Nov-03	2.600	0.190	0.190	0.090	0.060	0.040	0.040
9-Dec-03	3.200	0.110	0.100	0.040	0.020	0.020	0.010
13-Jan-04	5.600	0.150	0.150	0.070	0.040	0.030	0.020
3-Feb-04	2.200	0.140	0.140	0.080	0.070	0.070	0.060
2-Mar-04	2.300	0.110	0.100	0.050	0.030	0.020	0.020
31-Mar-04	3.700	0.140	0.130	0.060	0.040	0.030	0.020
12-May-04	2.700	0.110	0.110	0.050	0.030	0.020	0.020
2-Jun-04	3.600	0.110	0.110	0.050	0.030	0.020	0.020
6-Jul-04	0.700	0.030	0.030	0.020	0.010	0.010	0.010
18-Aug-04	1.300	0.030	0.030	0.010	0.010	0.010	0.010
8-Sep-04	4.000	0.070	0.070	0.030	0.020	0.010	0.010
4-Oct-04	1.100	0.060	0.060	0.030	0.020	0.010	0.010
26-Oct-04							
8-Dec-04	3.400	0.140	0.140	0.060	0.040	0.030	0.030
1-Feb-05	4.350	0.130	0.125	0.055	0.030	0.020	0.020
1-Mar-05	3.900	0.180	0.180	0.080	0.050	0.040	0.030
5-Apr-05							
Summary statistics using data from March 1st to October 1st only							
Min	0.700	0.010	0.010	0.010	0.010	0.010	0.010
Median	2.500	0.095	0.090	0.040	0.025	0.015	0.015

Table 10. Summary of 2002-05 Tsolum River DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	**DOC**	**UV**					
		250 nm	**254 nm**	**310 nm**	**340 nm**	**360 nm**	**365 nm**
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
22-Apr-02	3.500						
9-May-02							
27-May-02	2.400						
28-May-02							
24-Jun-02	1.750						
19-Aug-02	1.100						
30-Sep-02	1.500						
30-Oct-02	1.400	0.050	0.050	0.020	0.010	0.010	0.010
25-Nov-02	2.800	0.140	0.130	0.060	0.040	0.030	0.030
19-Dec-02	2.400	0.130	0.120	0.060	0.040	0.030	0.020
21-Jan-03	1.200	0.080	0.080	0.030	0.020	0.010	0.010
18-Feb-03	2.300	0.080	0.080	0.030	0.020	0.010	0.010
19-Mar-03	3.350	0.060	0.060	0.020	0.010	0.010	0.010
23-Apr-03	2.100	0.100	0.100	0.040	0.030	0.020	0.020
28-Jul-03	1.100	0.010	0.010	0.010	0.010	0.010	0.010
3-Sep-03	0.900	0.010	0.090	0.040	0.020	0.020	0.020
28-Oct-03	5.150	0.595	0.570	0.265	0.160	0.110	0.100
2-Dec-03	3.250	0.415	0.405	0.175	0.105	0.070	0.065
26-Jan-04	1.900	0.080	0.080	0.030	0.020	0.010	0.010
25-Feb-04	4.100	0.100	0.100	0.050	0.030	0.020	0.020
30-Mar-04	2.600	0.100	0.100	0.045	0.030	0.020	0.020
28-Apr-04	5.900	0.100	0.090	0.040	0.030	0.020	0.020
8-Jun-04	2.650	0.060	0.060	0.020	0.010	0.010	0.010
29-Jun-04	1.300	0.040	0.040	0.020	0.010	0.010	0.010
26-Jul-04	2.000	0.020	0.030	0.010	0.010	0.010	0.010
31-Aug-04	2.100	0.050	0.050	0.020	0.010	0.010	0.010
3-Nov-04	4.100	0.140	0.130	0.060	0.040	0.030	0.030
30-Nov-04	3.000	0.090	0.090	0.030	0.020	0.010	0.010
26-Jan-05	3.600						
2-Mar-05	3.000						
29-Mar-05	0.500						
25-Apr-05	3.000						
Summary statistics using data from March 1st to October 1st only							
Min	0.500	0.010	0.010	0.010	0.010	0.010	0.010
Median	2.100	0.055	0.060	0.020	0.010	0.010	0.010

Table 11. Summary of 2004-05 Little Qualicum River DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	DOC	UV					
		250 nm	254 nm	310 nm	340 nm	360 nm	365 nm
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
22-Jul-04	1.000	0.020	0.020	0.010	0.010	0.010	0.010
3-Aug-04	1.500	0.050	0.040	0.020	0.010	0.010	0.010
7-Sep-04	0.500	0.040	0.040	0.020	0.020	0.010	0.010
4-Oct-04	1.600	0.030	0.030	0.010	0.010	0.010	0.010
15-Nov-04	6.000	0.220	0.210	0.100	0.060	0.040	0.040
6-Dec-04	4.700	0.100	0.100	0.040	0.030	0.020	0.020
4-Jan-05	2.200	0.070	0.070	0.030	0.020	0.010	0.010
7-Feb-05	5.200	0.090	0.090	0.040	0.020	0.020	0.010
7-Mar-05	3.000	0.070	0.060	0.030	0.020	0.010	0.010
4-Apr-05	0.500	0.070	0.060	0.030	0.020	0.010	0.010
2-May-05	2.200	0.040	0.040	0.010	0.010	0.010	0.010
Summary statistics using data from March 1st to October 1st only							
Min	0.500	0.020	0.020	0.010	0.010	0.010	0.010
Median	1.250	0.045	0.040	0.020	0.015	0.010	0.010

Table 12. Summary of 2002-05 Englishman River DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	DOC	UV					
		250 nm	254 nm	310 nm	340 nm	360 nm	365 nm
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
2-Oct-02	1.500	0.030	0.020	0.010	0.010	0.010	0.010
5-Nov-02	2.200	0.030	0.030	0.020	0.010	0.010	0.010
4-Dec-02	2.400	0.060	0.060	0.020	0.010	0.010	0.010
8-Jan-03	2.600	0.100	0.100	0.040	0.030	0.020	0.020
6-Feb-03	3.100	0.080	0.070	0.030	0.020	0.010	0.010
5-Mar-03	3.700	0.060	0.060	0.020	0.010	0.010	0.010
1-Apr-03	3.200	0.090	0.090	0.040	0.020	0.020	0.010
12-May-03	1.500	0.040	0.040	0.010	0.010	0.010	0.010
2-Jun-03	2.700	0.030	0.030	0.010	0.010	0.010	0.010
7-Jul-03	1.800	0.020	0.020	0.010	0.010	0.010	0.010
5-Aug-03	1.600	0.010	0.010	0.010	0.010	0.010	0.010
4-Sep-03	2.900	0.580	0.600	0.620	0.640	0.650	0.660
1-Oct-03	1.900	0.010	0.010	0.010	0.010	0.010	0.010
4-Nov-03	2.500	0.280	0.270	0.120	0.080	0.060	0.050
13-Jan-04	2.700	0.090	0.090	0.040	0.020	0.020	0.010
11-Mar-04	1.800	0.070	0.060	0.030	0.020	0.010	0.010
7-Apr-04	2.000	0.050	0.050	0.020	0.010	0.010	0.010
6-May-04	0.700	0.050	0.050	0.020	0.010	0.010	0.010
2-Jun-04	2.500	0.030	0.030	0.010	0.010	0.010	0.010
8-Jul-04	1.300	0.030	0.020	0.010	0.010	0.010	0.010
3-Aug-04	1.700	0.040	0.040	0.010	0.010	0.010	0.010
31-Aug-04	1.400	0.020	0.020	0.010	0.010	0.010	0.010
5-Oct-04	1.300	0.030	0.030	0.020	0.010	0.010	0.010
3-Nov-04	4.400	0.130	0.120	0.060	0.040	0.020	0.020
7-Dec-04	3.900	0.130	0.120	0.050	0.030	0.020	0.020
5-Jan-05	2.300	0.090	0.090	0.040	0.030	0.020	0.020
1-Feb-05	3.700	0.090	0.090	0.040	0.020	0.010	0.010
4-Mar-05	3.800	0.080	0.070	0.030	0.020	0.010	0.010
Summary statistics using data from March 1st to October 1st only							
Min	0.700	0.010	0.010	0.010	0.010	0.010	0.010
Median	1.850	0.040	0.040	0.010	0.010	0.010	0.010

Table 13. Summary of 2002-04 Holland Creek DOC concentration and UVR absorbance data, with minimum and median values calculated for the period between March 1st and October 1st of each year. Highlighted values are those below the Minimum Detection Limit.

Parameter	DOC	UV					
		250 nm	254 nm	310 nm	340 nm	360 nm	365 nm
Unit	mg/L	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm	AU/cm
Date							
10-Jul-02	1.500						
7-Aug-02	1.600						
4-Sep-02	1.700	0.010	0.010	0.020	0.010	0.010	0.010
9-Oct-02	2.300	0.030	0.030	0.010	0.010	0.010	0.010
6-Nov-02	5.200	0.090	0.090	0.040	0.030	0.030	0.030
18-Dec-02	4.900	0.130	0.120	0.060	0.040	0.030	0.020
15-Jan-03	2.300	0.100	0.100	0.050	0.030	0.020	0.020
19-Feb-03	2.100	0.080	0.080	0.040	0.020	0.010	0.010
5-Mar-03	1.900	0.070	0.007	0.030	0.020	0.010	0.010
9-Apr-03	3.500	0.110	0.110	0.050	0.030	0.020	0.020
28-May-03	2.100	0.090	0.090	0.040	0.030	0.020	0.020
19-Jun-03	2.700	0.060	0.060	0.030	0.020	0.010	0.010
9-Jul-03	2.800	0.050	0.050	0.020	0.010	0.010	0.010
21-Aug-03	2.600	0.030	0.030	0.010	0.010	0.010	0.010
4-Sep-03	1.500	0.100	0.100	0.020	0.010	0.010	0.010
12-Nov-03	2.000	0.320	0.310	0.160	0.110	0.090	0.080
3-Dec-03	3.300	0.450	0.440	0.190	0.120	0.080	0.080
14-Jan-04	3.500	0.120	0.110	0.050	0.030	0.020	0.020
11-Feb-04	2.700	0.080	0.080	0.040	0.020	0.020	0.020
3-Mar-04	1.900	0.080	0.070	0.030	0.020	0.010	0.010
Summary statistics using data from March 1st to October 1st only							
Min	1.500	0.010	0.007	0.010	0.010	0.010	0.010
Median	1.900	0.070	0.060	0.030	0.020	0.010	0.010