Canadian Water Quality Guidelines for the Protection of Aquatic Life

COLOUR

Anthropogenic activities such as forest management, road building, construction, dredging, gravel pit operations, and industrial waste management may cause marked changes in physical, chemical, and biological characteristics of watercourses located nearby and those downstream. Changes in water colouration may be used as an indicator of environmental impact arising from anthropogenic activities.

The observed colour of water is the result of light backscattered upward from a water body after it has passed through the water to various depths and undergone selective absorption. The colour of light (i.e., wavelength) and the turbidity of water determine the depth to which light penetrates in water systems. In pure water, light is highly absorbed in the infrared region of the light spectrum and poorly absorbed in the blue region. Thus, blue light is refracted, reflected and/or re-emitted back, causing the visible colour of the water to be blue (Jerome et al. 1994a, 1994b).

The colour of water may be characterized as true or apparent. True colour depends on the dissolved fraction of water, which can include natural minerals such as ferric hydroxide and dissolved organic substances such as humic or fulvic acids (Hongve and Akesson 1996). Dyes (e.g., acid blue toilet flush), wood preservatives, antisapstains, and various other dissolved organic substances from anthropogenic sources may also contribute to water colouration (McCrum 1984; Brown 1987; Borgerding and Hites 1994). Organic compounds such as humic acids selectively absorb UV blue and green wavelengths and, to a lesser degree, the red and infrared region of the light spectrum. Colour also depends on factors that affect the solubility and stability of the dissolved and particulate fractions of water such as pH and temperature.

True colour can be measured by comparator and calorimetric methods. Comparator methods rely on visual comparison of a water sample to a standard colour solution, usually containing platinum (Pt) and cobalt (Co) chloride salts, or to a set of coloured filter disks. Calorimetric methods are based on the calibration of absorbance of the water sample at various single wavelengths, usually against the Pt-Co standard (Bennett and Drikas 1993; Hongve and Akesson 1996). Natural waters range from <5 mg·L^{-1} Pt in very clear waters to 1200 mg·L^{-1} Pt in dark, peaty waters (Kullberg 1992).

Apparent colour of water is a function of dissolved and suspended material, such as organic plant debris, phyto- and zooplankton, and inorganic suspended sediments (Effler and Auer 1987; APHA 1992; Bennett and Drikas 1993). For example, a blue-green water colour may be due to blue-green algal blooms, a yellow-brown colour to diatoms or dinoflagellates, and red and purple colours to *Daphnia* sp. or copepods (Chapman 1992). As these organisms thrive on some anthropogenic releases or disturbances (e.g., fertilizers and forest activities), polluted waters may have a strong apparent colour. In addition, land use activities such as logging may affect apparent colour by increasing turbidity (Bilby and Bisson 1992). Apparent colour is commonly estimated by light transmittance through water, as measured by Secchi disk depth.

Numerous monitoring studies have demonstrated a strong positive correlation between primary production and water colour in freshwater (Henebry and Cairns 1984; Arvola 1986; Ilmavirta and Huttunen 1989; Del Giorgio and Peters 1994). The colour of water may also affect algal species composition, as photosynthetic efficiency at various wavelengths differs markedly among algal groups according to the amounts of accessory pigments accompanying chlorophyll *a* (Atlas and Bannister 1980; Arvola 1986; Sheath et al. 1986; Vegas-Vilarrubia 1995). Humic-stained lakes (150 mg·L^{-1} Pt) in Finland have larger populations of blue-green algae, motile, and overall higher species richness than clear lakes (5 mg·L^{-1} Pt) (Ilmavirta and Huttunen 1989).

Few studies have quantified the effects of colour on estuarine and marine primary producers. A strong negative relationship was found between water colour and cell density of an estuarine diatom *(Phaeodactylum*

Table 1. Water quality guidelines for colour for the protection of aquatic life (Moore et al. 1997a).

Aquatic life—Freshwater, estuarine, and marine
True Colour The mean absorbance of filtered water samples at 456 nm shall not be significantly higher than the seasonally adjusted expected value for the system under consideration.
Apparent Colour The mean percent transmission of white light per metre shall not be significantly less than the seasonally adjusted expected value for the system under consideration.

tricornutum) in lab experiments employing water from an Australian lake (Haynes et al. 1994). Sources of colour to the lake water included domestic, industrial, and pulp and paper mill effluents. A change in water colour from 10 to 50 mg·L^{-1} Pt caused a 15.3% reduction in algal cell density. Coloured pulp and paper mill effluents have also been found to reduce algal productivity in areas with poor flushing along the coast of British Columbia. For example, minus a humic-stained effluent with a colour of 1000 mg·L^{-1} Pt discharged from a British Columbia mill to upper water layers prevented photosynthesis in sub-halocline phytoplankton at the head of Alberni Inlet (Parker and Sibert 1976).

Many invertebrate species possess visual receptors with absorption spectrum peaks that correspond to the spectral quality of their preferred habitats. For example, opossum shrimp *(Mysis* sp.*)*, which are found only in deep, clear, photically blue environments, have an absorption spectrum peak in their visual receptors at 515 nm (Wetzel 1975). Other species such as the freshwater prawn *(Macrobrachium rosenbergii)* have a strong behavioural preference for dark-coloured backgrounds, likely because they perceive dark colours as a refuge (Juarez et al. 1987). Freshwater fish species typical of photically blue environments (e.g., clear, deep lakes) have more visual receptors in the blue and green portions of the visible spectrum (Wetzel 1975). Changes in the spectral quality of water, therefore, could have profound effects on the behaviour of some invertebrate and fish species.

Most studies on the effects of water colour on fish have focused on the interaction between colour and toxicity of metals. Several studies have shown that aluminum, zinc, and copper complex with humic substances in coloured water, thus reducing toxicity (Wilson 1972; Nilssen 1982; Winner 1985; Hutchinson and Sprague 1987). The combined LC_{50} for a mixture of Al/Zn/Cu to flagfish declined by a factor of 2.1 when apparent colour (i.e., water samples were not filtered) increased from 3 to 10 mg·L^{1} Pt (Hutchinson and Sprague 1987).

Conversely, mercury availability, bioaccumulation, and, hence, toxicity increase as water colour increases (Mierle and Ingram 1991; Nilsson and Hakanson 1992; Haines et al. 1995). The reason for this relationship, in part, is that mercury brought to an aquatic system from the surrounding catchment area is attached to coloured substances (Mierle and Ingram 1991; Nilsson and Hakanson 1992). Also, in deep water systems, mercury methylation by bacteria under anoxic conditions will likely be enhanced with higher concentrations of humic matter (Nilsson and Hakanson 1992). For deep lakes in Sweden, regression analyses indicate that an increase in water colour from 10 to 50 mg·L^{-1} Pt was associated with an increase in mercury tissue levels in perch and pike of between 23.4 and 82.8% (Nilsson and Hakanson 1992).

Water Quality Guideline Derivation

The Canadian water quality guidelines for true and apparent colour were adopted from the ambient water quality criteria for colour in British Columbia (Moore et al. 1997a).

Freshwater and Marine Life

True Colour

Changes in the spectral quality of light in water may have a profound impact on primary productivity (Gallegos and Kenworthy 1996), phytoplankton species composition (Atlas and Bannister 1980; Ilmavirta and Huttunen 1989), and foraging behaviour and habitat selection of invertebrates and fish (Wetzel 1975; Juarez et al. 1987; Kullberg 1992). Therefore, any change in spectral quality of water as a result of an anthropogenic activity should be of concern. Changes in spectral quality are much more influenced by changes in true colour than by changes in concentrations of particulate matter, because the latter have relatively nonselective scattering properties. True colour, however, exhibits considerable spatial and temporal variability. It is not useful, therefore, to specify a single value as the ambient water quality guideline for apparent colour. The guideline for true colour is such that the mean absorbance at 456 nm of filtered water samples shall not be significantly higher than the seasonally adjusted expected value for the system under consideration. This guideline applies to freshwater, estuarine, and marine aquatic systems.

The appropriate wavelength range for determining spectral quality and, hence, true colour should be in the blue portion of the spectrum because water absorption is low in this region and because humic and fulvic acids exhibit equal absorbance to the standard Pt-Co reference solution around 410 nm and 445–470 nm (Bennett and Drikas 1993; Hongve and Akesson 1996). A wavelength of 456 nm was chosen for the guideline because the influence of turbidity following filtration is negligible at this wavelength (Bennett and Drikas 1993). The sampling manual accompanying the British Columbia criteria document for turbidity and suspended and benthic sediments provides more detail on sampling and statistical approaches that may be used to determine whether an anthropogenic activity has adversely affected transmission of white light in an aquatic system (Moore et al. 1997b).

Apparent Colour

Relatively small increases in light attenuation by dissolved organic matter and/or suspended particulate may have a profound impact on the lower limit of the euphotic zone (Eloranta 1978). This effect may lead to reductions in primary productivity (Parker and Sibert 1976; Haynes et al. 1994; Christensen et al. 1996), coverage of submersed macrophytes (Orth and Moore 1983; McPherson and Miller 1987; Gallegos and Kenworthy 1996), and indirect impacts at higher trophic levels in both freshwater and estuarine systems (Kullberg 1992). Therefore, any increase in apparent colour, as a result of anthrogenic inputs, should be of concern.

Transmission of white light through water is a function of the two components of apparent colour, dissolved and particulate matter, and is therefore a useful monitoring tool for this parameter (Jerome et al. 1994a, 1994b). Like true colour, transmission of white light exhibits considerable spatial, year-to-year, and seasonal variation (Jerome et al. 1994a). It is not appropriate, therefore, to specify a single value as the ambient water quality criterion for apparent colour. A more suitable approach is to test whether a particular anthropogenic activity (e.g., road construction, harvesting of forests) is causing a significant decrease in transmission of white light compared to background conditions in nearby aquatic systems. The guideline for apparent colour, therefore, is such that the mean percent transmission of white light per metre shall not be significantly less than the seasonally adjusted expected value for the system under consideration. This guideline applies to freshwater, estuarine, and marine aquatic systems.

References

APHA (American Public Health Association). 1992. Standard methods for the examination of water and wastewater. 18th ed. APHA, Washington, DC.

Arvola, L. 1986. Spring phytoplankton of 54 small lakes in southern Finland. Hydrobiologia 137:125–134.

Atlas, D., and T.T. Bannister. 1980. Dependence on mean spectral extinction coefficient of phytoplankton on depth, water colour, and species. Limnol. Oceanogr. 25:157–159.

Bennett, L.E., and M. Drikas. 1993. The evaluation of colour in natural waters. Water Res. 27:1209–1218.

Bilby, R.E., and P.A. Bisson. 1992. Allochthonous versus autochthonous organic matter contributions to the trophic support of fish populations in clear-cut and old-growth forested systems. Can. J. Fish. Aquat. Sci. 49:540–551.

Borgerding, A.J., and R.A. Hites. 1994. Identification and measurement of food and cosmetic dyes in a municipal wastewater treatment plant. Environ. Sci. Technol. 28:1278–1284.

Brown, D. 1987. Effects of colorants in the aquatic environment. Ecotox. Env. Saf. 13:139–147.

Chapman, D. 1992. Water quality assessment: A guide to the use of biota, sediments and water in environmental monitoring. Chapman and Hall, London.

Christensen, D.L., S.R. Carpenter, K.L. Cottingham, S.E. Knight, J.P. LeBouton, D.E. Schindler, N. Voichick, J.J. Cole, and M.L. Pace. 1996. Pelagic responses to changes in dissolved organic carbon following division of a seepage lake. Limnol. Oceanogr. 41:553–559.

Del Giorgio, P.A., and R.H. Peters. 1994. Patterns in planktonic P:R ratios in lakes: Influence of lake trophy and dissolved organic carbon. Limnol. Oceanogr. 39:772–787.

Effler, S.W., and M.T. Auer. 1987. Optical heterogeneity in Green Bay. Water Resour. Bull. 23:937–942.

Eloranta, P. 1978. Light penetration in different types of lakes in central Finland. Holarctic Ecol. 1:362–366.

Gallegos, C.L., and W.J. Kenworthy. 1996. Seagrass depth limits in the Indian River Lagoon (Florida, U.S.A.): Application of an optical water quality model. Estuarine Coastal Shelf Sci. 42: 267–288.

Haines, T.A., V.T. Komov, V.E. Matey, and C.H. Jagoe. 1995. Perch mercury content is related to acidity and color of 26 Russian lakes. Water Air Soil Pollut. 85:823–828.

Haynes, D., P. Rayment, K. Raynes, and P.R.L. Mosse. 1994. Laboratory-based investigation into the potential for algal proliferation in Lake Coleman, Victoria. Aust. J. Mar. Freshwater Res. 45:625–634.

Henebry, M.S., and J. Cairns, Jr. 1984. Protozoan colonization rates and trophic status of some freshwater wetland lakes. J. Protozool. 31:456–467.

Hongve, D., and G. Akesson. 1996. Spectrophotometric determination of water color in hazen units. Water Res. 30:2771–2775.

Hutchinson, N.J., and J.B. Sprague. 1987. Reduced lethality of aluminum zinc and copper mixtures to American flagfish by complexation with humic substances in acidified soft waters. Environ. Toxicol. Chem. 6:755–766.

Ilmavirta, V., and P. Huttunen. 1989. Water chemistry and phytoplankton communities in acidic clear and brown-water lakes in eastern Finland. Water Air Soil Pollut. 46:415–432.

Jerome, J.H., R.P. Bukata, P.H. Whitfield, and N. Rousseau. 1994a. Colours of natural waters: 2. Observations of spectral variations in British Columbia rivers. Northwest Sci. 68:53–64.

———. 1994b. Colours of natural waters: 1. Factors controlling the dominant wavelength. Northwest Sci. 68:43–52.

Juarez, L.M., K.H. Holtschmit, J.J. Salmeron, and M.K. Smith. 1987. The effects of chemical and visual communication, space availability, and substratum color on growth of the juvenile fresh-water prawn *Macrobrachium rosenbergii* (De Man). J. Exp. Mar. Biol. Ecol. 110:285–295.

Kullberg, A. 1992. Benthic macroinvertebrate community structure in 20 streams of varying pH and humic content. Environ. Pollut. 78:103–106.

McCrum, W.A. 1984. The use of second-order derivative spectroscopy in the investigation of sources of colored pollutants in water. Water Res. 18:1249–1252.

McPherson, B.F., and R.L. Miller. 1987. The vertical attenuation of light in Charlotte Harbor, a shallow, subtropical estuary, south-western Florida, USA. Estuarine Coastal Shelf Sci. 25:721–737.

Mierle, G., and R. Ingram. 1991. The role of humic substances in the mobilization of mercury from watersheds. Water Air Soil Pollut. 56:349–357.

Moore, D.R.J., P.-Y. Caux, and N. Nagpal. 1997a. Ambient water quality criteria for colour in British Columbia. Technical appendix. Ministry of Environment, Lands and Parks, Victoria, BC.

———. 1997b. Sampling strategy for turbidity, suspended and benthic sediments in British Columbia. Technical appendix addendum. Ministry of Environment, Lands and Parks, Victoria, BC

Nilssen, J.P. 1982. Acidification in southern Norway: Seasonal variation of aluminum in lake waters. Hydrobiologia 94:217–222.

Nilsson, A., and L. Hakanson. 1992. Relationships between mercury in lake water, water colour and mercury in fish. Hydrobiologia 235/236:675–683.

Orth, R.J., and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. Science 222:51–53.

Parker, R.R., and J. Sibert. 1976. Responses of phytoplankton to renewed solar radiation in a stratified inlet. Water Res. 10:123–128.

Sheath, R.G., M.O. Morison, J.E. Korch, D. Kaczmarczyk, and K.M. Cole. 1986. Distribution of stream macroalgae in south-central Alaska USA. Hydrobiologia 135:259–270.

Vegas-Vilarrubia, T. 1995. Distribution of the phytoplankton from the Guri reservoir (Venezuela). Hydrobiologia 310:33–46.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, Philadelphia.

Wilson, R.C.H. 1972. Prediction of copper toxicity in receiving waters. J. Fish. Res. Board Can. 29:1500–1502.

Winner, R.W. 1985. Bioaccumulation and toxicity of copper as affected by interactions between humic acid and water hardness. Water Res. 19:449–455.

Reference listing:

Canadian Council of Ministers of the Environment. 2001. Canadian water quality guidelines for the protection of aquatic life: Colour. Updated. In: Canadian environmental quality guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

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