5.6 Black Carbon in air

Author, affiliation: Guy Coulson (NIWA), Elizabeth Somervell (NIWA), Emily Wilton (Environet Ltd)

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Preamble: Black Carbon (BC) is a component of particulate matter (PM_{10}) as is defined by WHO 2012 as follows: "*BC is an operationally defined term which describes carbon as measured by light absorption. As such, it is not the same as elemental carbon (EC), which is usually monitored with thermal optical methods*".

Elemental carbon (EC) in atmospheric PM derived from a variety of combustion sources contains the two forms "char-EC" (the original graphite-like structure of natural carbon partly preserved, brownish colour) and "soot-EC" (the original structure of natural carbon not preserved, black colour) with different chemical and physical properties and different optical light-absorbing properties.

A thermal optical reflectance method can be applied to differentiate between char-EC and soot-EC according to a stepwise thermal evolutional oxidation of different proportions of carbon under different temperatures and atmosphere (WHO 2012).

State of knowledge of "Black Carbon in air" attribute: Good / established but incomplete – general agreement, but limited data/studies

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Black carbon is formed through the incomplete combustion of fossil fuels, biofuel and biomass, and is emitted from both anthropogenic and natural sources. It is a component of particulate matter. The key impacts of black carbon are on human health and climate. It also contributes to brown haze through particle light absorption and was found to contribute around 25% of the brown haze in Christchurch in the early 2000s (Wilton, 2003) Health impacts of black carbon include short-term (24-hour) and long-term (annual) exposure impacts on cardiovascular health effects and premature mortality, and are independent of $PM_{2.5}$ impacts (World Health Organization, 2021). Elemental carbon (of which black carbon is a component) is a known carcinogen as a result of carcinogens within combustion processes condensing on the BC particles (World Health Organization, 2021).

Black carbon is a powerful climate-warming agent that acts by absorbing heat in the atmosphere and by reducing the ability to reflect sunlight when deposited on snow and ice (Bond et al., 2013). It is a Short Lived Climate Pollutant (SLCP), also referred to as a Short-lived Climate Forcer by the Intergovernmental Panel on Climate Change (IPCC, 2024). It's lifetime in the atmosphere is days to weeks.

A2. What is the evidence of impact on (a) ecological integrity or (b) human health? What is the spatial extent and magnitude of degradation?

Evidence for the health impacts of BC has been available for at least the past decade. For example, WHO 2012, states:

> "The systematic review of the available time-series studies, as well as information from panel studies, provides sufficient evidence of an association of short-term (daily) variations in BC concentrations with short-term changes in health (all-cause and cardiovascular mortality, and cardiopulmonary hospital admissions). Cohort studies provide sufficient evidence of associations of all-cause and cardiopulmonary mortality with long-term average BC exposure."

However, due to a lack of sufficiently detailed spatial measurements, there is still not enough epidemiological data to be able to set exposure guidelines (WHO 2021).

Monitoring data for New Zealand shows that BC concentrations vary both temporally and spatially (Davy & Trompetter, 2017).

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Receptor modelling results indicate that diesel vehicle emissions and biomass combustion are the primary sources of BC in New Zealand urban areas (Davy & Trompetter, 2017). Concentrations have been gradually improving in the few areas with sufficient records for trend determination as a result of improvements in motor vehicle and solid fuel burning BC concentrations (Davy & Trompetter, 2017).

The National Environmental Standards for Air Quality (NESAQ) require wood burners to meet a specified emission and energy efficiency criteria if they are to be installed on properties less than 2 hectares in area from 2005. The latter is likely to have ongoing impact on BC concentrations as older less efficient burners are replaced with more efficient and lower emission alternatives. Many Regional Councils have adopted additional measures to reduce urban particulate from solid fuel burning which may also accelerate reductions in BC.

Existing central government policies targeting motor vehicles are likely to result in reductions in BC from this source over the next 10-30 years. The impact of changes in vehicle fleet composition, including increased electric vehicle use, on tailpipe $PM_{2.5}$ emissions which include a BC component are integrated into the national vehicle fleet emission model[1] (VEPM 7.0) (New Zealand Transport Agency, 2019). This model indicates a 95% reduction in tailpipe $PM_{2.5}$ emissions from motor vehicles over the next 26 years (VEPM with default model parameters). Waka Kotahi also aim to reduce total

1 Whilst VEPM includes assumptions around integration of Euro 6/VI vehicles these may not reflect the impact of existing policy and thus improvements may be underestimated.

kilometres travelled by the light fleet by 20% by 2035 through improved urban form and providing better travel options (Waka Kotahi, 2024) and this will result in further improvements in BC from motor vehicles.

Impacts of air contaminants such as black carbon are not typically reversable if they contribute to development of chronic impacts through long term exposure.

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

In Aotearoa, there is no requirement to monitor BC, as there are no relevant NESAQ, ambient air quality guidelines nor a WHO guideline and thus there is limited monitoring. Continuous real-time measurements are carried out in Auckland (Customs St) and Wellington (Willis St) and in Christchurch. NIWA and others have carried out campaign based monitoring at various locations, including mobile monitoring (e.g., Olivares et al., 2007).

There is not a New Zealand standard method for black carbon monitoring. Methods used tend to focus on optical approaches including real time aethalometer measurement of absorption by particles (Wilton, 2003) and filter based measurements of light absorption by particles (Davy & Trompetter, 2017). Measurement is complex. Light absorption is only a proxy (indirect technique) for black carbon and direct method measurement systems require complex thermal systems (Wilton, 2003). The mass concentration of BC obtained using different methods varies significantly which confounds impact assessment (Zhang et al., 2023).

Statistics New Zealand report black carbon concentrations in New Zealand for the Auckland monitoring sites on their website under the indicators programme(Statistics New Zealand, 2024). GNS have prepared several reports indicating results of black carbon filter analysis including sources and trends (Davy & Trompetter, 2017, 2018).

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

BC monitoring is usually carried out at existing air quality monitoring sites, so access is not usually problematic.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

An optical instrument such as an aethalometer will cost several tens of thousands of dollars – typically $30,000 to $60,000. Operating costs tend to be minimal at less than a few thousand dollars per year typically.

Indirect measurement methods should be calibrated in-situ to more closely account for source and site related variables impacting on the estimates, which can add to costs. In practice, most users rely on the manufacturer's calibration supplied with the instrument. These are not overly reliable (Zhang et al., 2023). Filter based methods are also impacted on by multiple scattering effects of the filter and particles (Zhang et al., 2023)

Thermal optical methods are the most commonly used approach in the larger European programmes (Zhang et al., 2023). These use temperature to differentiate carbon components and there are still complexities in the assessment. Thermal optical instruments tend be much more expensive (> $100,000).

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

We are not aware of any Black Carbon monitoring being undertaken by iwi/hapū/rūnanga.

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

The correlation between black carbon and $PM_{2.5}$ concentrations is likely to be high as BC is a subset of $PM_{2.5}$ (Boamponsem et al., 2024). Variability in the relationship is likely to be greatest in areas where both motor vehicles and biomass burning are major sources of $PM_{2.5}$ owing to varying contributions of these sources to organic carbon emissions to $PM_{2.5}$.

Source apportionment studies carried out in New Zealand show black carbon is typically within the biomass burning and motor vehicle source profiles as a significant contributor but is also present in the marine aerosol profiles (e.g., (Ancelet et al., 2015). BC can be correlated with other combustion related air contaminants. However, the ratios of contaminants discharged varies with source, confounding ambient air correlations.

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The current state is moderately understood in a small number of locations within Auckland, Wellington and Christchurch. Measurements have also been undertaken on daily filters used in short term (typically around a year) source apportionment studies, in up to ten additional locations.

Whilst some air quality data are nationally available on the LAWA website (https://www.lawa.org.nz/), BC is not included.

Greater Wellington Regional Council and Auckland council publish data on their websites (https://gwrc-open-data-11-1-gwrc.hub.arcgis.com/, https://knowledgeauckland.org.nz/)

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

The largest natural source of BC is wildfires but there are no known background measurements in Aotearoa to act as a baseline.

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

There are currently no guidelines for ambient BC concentrations, but it can be managed indirectly through standards and guidelines for PM_{10} and $PM_{2.5}$. More extensive monitoring internationally is required to better characterise health impacts and evaluate appropriate guideline.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity or human health?

BC is a component of $PM_{2.5}$ for which there is no known safe threshold for adverse health impacts. Studies showing independent impacts of BC in conjunction with $PM_{2.5}$ are limited, and no health-based threshold has been identified. BC is a climate pollutant and hence contributes to any climate tipping points or thresholds.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Some health studies for air contaminants report lag effects between exposures and health endpoints. These do not impact on state or trend assessments. Because BC is carcinogenic, there may be considerable lag times of decades before effects reveal themselves.

However, because BC is a short-lived pollutant with an atmospheric lifetime of days to weeks, removal of sources will effectively remove any future impacts – this is also true of climate effects. An exception to this would be contributions to disease prevalence and increased frailty which could contribute to health impacts that occur sometime after exposures.

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

Good air is considered a taonga and Māori are often disproportionately affected by poor air quality ((Telfar Barnard & Zhang, 2018)). However, whilst air as a taonga is often mentioned in iwi environmental strategies, we are not aware of any iwi explicitly planning to reduce air pollution exposure of their members.

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

MfE regularly publishes a SOE report on air quality, most recently in 2021. Whilst this does not include BC, it does include PM_{10} and $PM_{2.5}$, of which BC is a subset. Analysis undertaken by GNS shows BC to be most strongly associated with the biomass burning and motor vehicle source profiles in New Zealand and notes that the dominant contributor varies with location and proximity of monitoring site to roadside (Davy & Trompetter, 2017). The pressures and drivers of $PM_{2.5}$ are reasonably well understood as are (at a general or high level) the response and state. The relationship between emissions and concentrations is spatially and temporally dependent primarily influenced by meteorology and topography. These variables all impact on exposure and subsequent health effects are also influenced by underlying susceptibility (Figure 1).

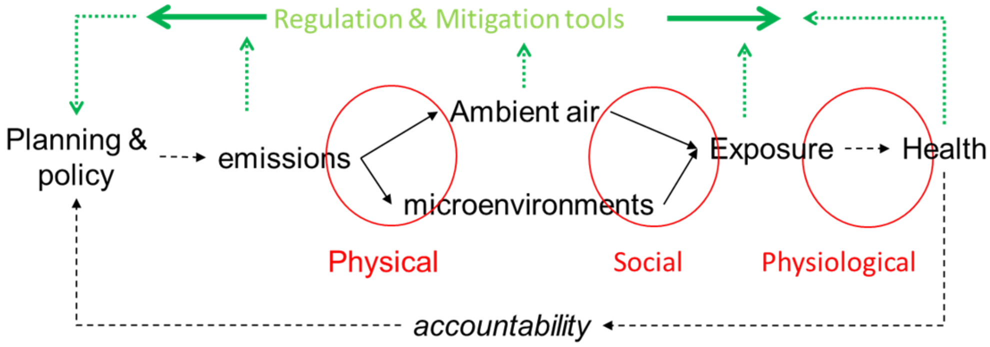

Figure 1. links in the chain from pollutant emissions to health effects

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

There is no NESAQ or other guideline for BC, however any interventions aimed at co-emitted pollutants will have an impact on BC concentrations. These include measures targeting domestic heating and motor vehicles in New Zealand.

C2-(ii). Central government driven

The NESAQ design criteria for wood burners was established for the purpose of reducing concentrations of particulate in urban areas. The impact of this legislation is ongoing in most areas as households replace older more polluting and less efficient burners with compliant models over time. Additionally, many Regional Councils have adopted regulatory measures targeting domestic heating to further improve or accelerate reductions in urban particulate concentrations. BC concentrations are likely to reduce in conjunction with $PM_{2.5}$.

The impact of national measures targeting other contaminants (e.g., fuel and technology specifications) and greenhouse gas emissions from motor vehicles is likely to also impact on black carbon concentrations from this source. Roadside monitoring of black carbon in Wellington CBD shows a reduction in BC concentrations from 2016 to 2023 (https://www.gw.govt.nz/your-council/open-data/).

The Ministry for the Environments 2021 state of the environment report found concentrations of $PM_{2.5}$ to be improving in four out of eight sites from 2011 to 2020 with three sites being indeterminate and one site showing worsening concentrations (Ministry for Environment, 2021).

C2-(iii). Iwi/hapū driven

Iwi/hapū planning documents such as Environmental Management Plans and Climate Change Strategies/Plans may contain policies/objectives/methods seeking to influence air quality outcomes for the benefit of current and future generations. We are not aware of other interventions/mechanisms being used by iwi/hapū/rūnanga to directly affect this attribute.

C2-(iv). NGO, community driven

Most community air quality projects we are aware of have concentrated on particle concentrations, usually from wood burning of which BC is a subset. NIWA has conducted numerous community collaborations on particles, but we are not aware of any directly targeting BC.

C2-(v). Internationally driven

The global driver and lead of air quality guidelines and management strategies is the WHO. Aotearoa's NESAQ were largely based on WHO guidelines published in the 1990s (and reaffirmed in 2005). In 2021 the WHO substantially revised its guidelines, setting much lower values for many pollutants but could not give guidance for BC. It did recommend that regulatory bodies take responsibility for monitoring BC in order to create sufficient evidence to set guidelines in future.

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Existing air quality management including measures targeting domestic heating and motor vehicles are likely to result in ongoing improvements in black carbon. Further management may be required for health protection noting that Māori continue to be disproportionately impacted. Contributions to environmental impacts such as brown haze in Auckland and Christchurch may continue.

Climate impacts: BC has a 1600 times greater global warming potential than CO_2. Therefore, if BC is not managed it will directly contribute to the climate crisis until it is.

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

Health and consequently economic impacts of BC exposure in New Zealand will be greatest in urban areas where concentrations of particulate are high and in areas near to roadways. Māori are disproportionately affected by respiratory and cardiovascular disease (Mason et al., 2019; Telfar Barnard & Zhang, 2018) and will be more susceptible to the health impacts of BC exposure.

Contribution of BC to visibility degradation could have economic impacts by way of reduced tourism for areas such as Christchurch and Auckland where brown haze is noticeable.

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

This attribute contributes to climate change and will be affected by it. A warmer climate increases the risk of wildfire which is a source of BC. There is the potential that BC concentrations in urban areas may decrease slightly as a result of climate change. This may occur if climate change results in fewer ground frosts as the associated low wind speeds and decreased vertical dispersion increase the potential for degraded air.

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