Living Brooklyn:

Baseline report on the economics of the urban water cycle in the Brooklyn Industrial Precinct

Roger N Jones and Daniel Ooi

Victoria University



VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

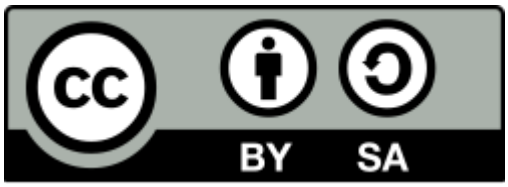
Acknowledgements

Data for this report was kindly provided by the Victorian EPA, Brimbank City Council, City West Water, E2 Design and VicRoads. Other data was sourced from the Bureau of Meteorology and the Australian Bureau of Statistics. Project Manager Tashia Dixon is thanked for support in gathering key data, in addition to Brimbank City Council staff and staff from all the organisations mentioned above, who provided invaluable assistance. Project funding from the Office of Living Victoria and project sponsored by the City of Brimbank.

Contact

Roger Jones
Victoria Institute of Strategic Economic Studies
Victoria University
PO Box 14428
Melbourne, Victoria, 8001
Australia
Email roger.jones@vu.edu.au

© 2014 Victoria University
This work is licensed is licensed under CC BY-SA 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-sa/4.0/



Suggested citation

Jones, R.N. and Ooi, D. (2014) Living Brooklyn: Baseline report on the economics of the urban water cycle in the Brooklyn Industrial Precinct. Victoria Institute of Strategic Economic Studies, Victoria University, Melbourne, 42 pp.
DOI: 10.5281/zenodo.23931734



Executive summary

This report explores the social and ecological systems influencing the water cycle within the Brooklyn Industrial Precinct. It seeks to:

- establish the direct and indirect monetary costs of health impacts of dust and odour,
- identify social and environmental values associated with the urban water cycle and
- aims to set a baseline that can serve as the basis for analysing and identifying potential integrated water cycle management strategies for the Brooklyn Industrial Precinct.

Three systems of value have been identified:

1. The on-site urban water system.
2. The Kororoit Creek catchment.
3. The airshed linked to the precinct.

1. Key aspects of the precinct urban water system relevant to values on the site are:

- High levels of water use by some customers provide the potential for substitution by alternative water sources and from site design.
- The limited water infrastructure onsite leads to poorly controlled drainage and flooding and sediment problems in many areas.
- High levels of runoff, sediment and nutrients from the site affect adjacent waterways, degrading environmental values.

2. Kororoit Creek is an important urban waterway:

- The precinct reduces the visual amenity of the creek and the physical amenity of the eastern side of the creek valley due to the encroachment of fill into the valley.
- Intercepting sediment and nutrients entering the creek waters is an important part of addressing the Kororoit Creek Regional Strategy 2005–2030.
- Initial data suggests that there are cost-effective options for limiting poorly controlled runoff, sediments and nutrients from the site, improving environmental values within the catchment.

3. The Brooklyn Industrial Precinct Airshed

The major focus of this report is dust and aerosol production within the Brooklyn Industrial Precinct, affecting the health and wellbeing of adjacent residents. Exhaustive analysis of EPA monitoring data, local rainfall data and traffic data provides a precise picture of the water, sediment, transport and dust cycle contributing to the generation of airborne dust and aerosol particles. Combined with health modelling, we have assessed a range of direct monetary and indirect social costs, which can become benefits if air pollution is reduced.

Dust and aerosol production and levels

- Two EPA monitoring stations, Brooklyn and Footscray, register pollution peaks that can be directly attributed to the precinct. Brooklyn experiences an average of 28 days per year of PM10 >50, exceeding the legislated limit of 5 days per year. Footscray experiences 3 days on average.
- High rates of air pollution at Brooklyn are associated with winds coming from the NW to NE and time of day, being highest at 8–9 am. High pollution occurs on weekdays and moderate pollution on Saturdays, all linked to transport movement. At Footscray high pollution occurs with westerly winds, with similar timing to Brooklyn.

- For Brooklyn, average PM10 levels are 35.5 µg/m^3 when winds are from the north and 19.6 µg/m^3 when winds are from other directions. At Footscray, average PM10 levels are 23.2 µg/m^3 when winds are from the west and 18.2 µg/m^3 when winds are from other directions.
- Wind rarely initiates significant pollution events on its own, as shown by the low number of exceedances on Sunday (1.4% of total hourly exceedances of PM10 >50 µg/m^3).
- Atmospheric conditions are vital for the persistence high PM10 levels, especially wind direction, wind speed and atmospheric stability. Northerly winds and stable conditions produce high PM10 levels at the Brooklyn site. During the day, atmospheric instability increases, causing pollution to rise and disperse. The situation is similar with westerlies at Footscray.
- For Brooklyn, average PM2.5 levels are 7.2 µg/m^3 when winds are from the north and 6.2 µg/m^3 when winds are from other directions. For Footscray, there is essentially no difference, with no meaningful contribution of PM2.5 from the precinct.

The role of sediments and moisture

- Sediment supply and movement is critical for the production of dust and aerosols.
- Aerosols will be produced by traffic if roads are dry and sediment is present. Watering can suppress dust but only temporarily, as transport will rapidly dry roads out.
- Sediment containing some moisture is more likely to adhere to vehicles than dry sediment. Although wetting down sediment will hamper dust production, it promotes sediment redistribution. In wet conditions, mud will be tracked further from sites onto main roads.
- Sediment transport within lots and onto roads is a perennial problem. Dust suppression using water has limited effectiveness because it does not address sediment production and transport.
- The best strategies will be those that combine road and drainage improvements, site modification, sediment stabilisation, wheel washes and transport movement plans, and use dust suppression with water as a last resort.

Health and wellbeing

- Even though the difference between PM10 levels from the precinct is much higher than for PM2.5, the health impacts of PM2.5 are larger.
- If at Brooklyn, winds are blowing from the north quarter (NW to NE) the likelihood of PM10 >50 is 62% at 9 am. At midday, this probability is 42%, a level sustained to 3 pm. By 6 pm, even if the winds are still from the north, the likelihood of exceeding PM10 >50 falls to 11%.
- Given wind direction and estimates of atmospheric stability, it is possible to develop accurate estimates of likely exposure to PM10 over the course of a day.
- Estimated increased mortality due to particulates from the precinct is 1.4 persons per year with a range of 0.9 to 1.9. Estimated increased asthma hospitalisations due to particulates from the precinct is 0.5 with a range of 0.2 to 0.7. Up to 85 extra person may be affected by asthma due to added pollution levels.
- Workers on the site will be affected by even higher levels of particulates than measured at the Brooklyn monitoring station, but we currently have no information as to their number, vulnerability or tenure at the site, by which to judge exposure.

Direct and indirect costs

- Collated monetary costs are $859,000 for 2013–14. Most of which is for dust suppression and compliance. Health costs are only a small part of this total but it lacks estimates for heart-related illness and hospitalisation due to elevated air pollution.
- Social costs from mortality are estimated as being equivalent to $10.7 million per year ranging from $6.3 to $13.6 million.

- Equivalent costs for social wellbeing have a central estimate of $29 million per year but range from $23.5 million to $53.9 million. These are not direct costs to the economy but are value-equivalent measures based on relationships between income, happiness and wellbeing. These costs would become benefits if pollution were to be abated through management actions.
- Total social cost per annum of air pollution from the precinct is equivalent to $39.7 million with a range of $29.8 million to $67.5 million. While this dwarfs direct health costs and costs of maintenance, suppression and compliance, removing air pollution as part of an integrated water systems strategy would deliver these costs as social benefits, to be accrued over the long term.

Contents

Executive summary iv

1 Social and ecological framework 1

1.1 Background 1

1.2 Physical setting 2

1.3 Key impacts, systems, values and major drivers 2

1.4 Impact-response framework 3

2 Subsystems and values 6

2.1 Brooklyn Industrial Precinct urban water system 6

2.2 Kororoit Creek and catchment 7

2.3 Brooklyn Industrial Precinct airshed 8

3. Air quality assessment 14

3.1 PM10 14

3.2 PM2.5 22

3.3 Dust and odours 23

4. Social and environmental costing 25

4.1 Rationale and aims of social and environmental impact accounting 25

4.2 How social impacts are assessed in this report 26

4.3 Data sources, limitations and assumptions 26

5 Cost to the community 27

5.1 Exceedance of safe levels of PM2.5 and PM10 27

5.2 Direct health costs of dust 32

5.3 Indirect health costs of dusts and odour 34

5.4 Compliance costs 36

5.5 Environmental costs 36

5.6 Direct and indirect costs 37

6 Conclusions 38

6.1 The Brooklyn Industrial Precinct Urban Water System 38

6.2 The Kororoit Creek Catchment 38

6.3 The Brooklyn Industrial Precinct Airshed 38

References 41

1 Social and ecological framework

1.1 Background

The Living Brooklyn Project led by Brimbank City Council and funded by the Office of Living Victoria is a two-year project to be completed by June 2015. The project goal is to develop a vision for an integrated water cycle management (IWCM) plan for the Brooklyn Industrial Precinct. This is based on the overall vision established in the Brooklyn Evolution structure plan and urban design framework (Meinhardt Infrastructure & Environment and McGauran Giannini Soon, 2012):

> *Over the next 20 years, the Brooklyn Industrial Precinct will evolve into a key employment node for Melbourne's west, a destination of choice for new, 'clean and green' investment and development.*

The project is centred on the Brooklyn Industrial Precinct within the municipal boundaries of Brimbank City Council. The precinct adjoins Maribyrnong, Hobsons Bay and Wyndham City Councils. The precinct is part of the Western Industrial Node, 12 km west of Melbourne CBD. The precinct comprises approximately 262 ha of industrially-zoned land which hosts over 60 industries. These industries include quarrying, former landfills, abattoirs, composting, materials recycling, tallow producers, container storage and former chemical manufacturing, as well as numerous smaller retailers and manufacturers. Approximately 200 businesses are located within the precinct.

This report is one of two being prepared for a baseline study that aims to provide a clear and comprehensive picture of the role water plays in the Brooklyn precinct. These reports will provide the basis for an IWCM plan that addresses the current limitations of the existing water system at Brooklyn Industrial Estate. This plan will be established through a visioning process involving key stakeholders from industry, community and the government.

A core issue to be addressed through an IWCM plan is to analyse and identify potential management strategies for Brooklyn Industrial Precinct's air quality issues, which are the most acute in Melbourne. Although improvements have been made over years due to remediation and increased compliance, health risks remain significant to onsite employees and adjacent residents (EPA, 2011, 2012, 2013a). Currently, potable water is used to suppress dust as the most cost-effective measure. The cost to businesses of not using water to suppress dust is enforcement through VCAT or prosecution by either the EPA and/or Council.

This report explores the baseline social and ecological systems influencing the water cycle within the Brooklyn Industrial Precinct, especially aspects influencing the generation and management of dust and aerosols. The analysis has been carried out by Victoria University with support from Brimbank City Council and government agencies. It is one of two technical reports, the other being carried out by E2 Design on water supply, generation and use within the Brooklyn Industrial Precinct (Browne and Brookes, 2014). This will be referred to as the E2D Report.

This report provides a social costing of the baseline case for the Living Brooklyn project. It estimates direct and indirect monetary costs of health impacts of dust and odour on the site, using available evaluation methods for undertaking such tasks. In cases where established relationships do not exist, the assessment is qualitative. The report also addresses existing compliance costs where available and broader environmental values related to IWCM within the Precinct.

1.2 Physical setting

The physical setting for the Brooklyn Industrial Precinct is comprehensively described in the E2D Report (Browne and Brookes, 2014) and is summarised here:

- Land use ranges from retail, warehouses, factories and abattoirs with large roofs, to open storage areas as well as landfill, materials recycling and quarry sites with disturbed soils and frequent traffic and reworking. A number of landfill sites are in the process of being closed and stabilised through revegetation. There are large areas of vacant land.
- Several roads within the precinct are unsealed, including Jones Road and the western end of Bunting Road. Other roads have a narrow band of tarmac with unsealed verges. Council propose to seal these roads within the next two years with a $900,000 contribution from the Victorian Sustainability Fund.
- The precinct is nominally located within the Werribee River catchment and has three main sub-catchments: Burgess Drain, Kororoit Creek (lower) and Stony Creek (lower). The Burgess Drain and Kororoit Creek catchments drain to Kororoit Creek; Stony Creek lower drains to Stony Creek. Both Stony and Kororoit Creeks drain in Port Phillip Bay.
- The Melbourne Outfall Sewer and Federation Trail bicycle and walking trail passes through the precinct. The trail links Werribee to Brooklyn and the Kororoit Creek corridor and is being connected to the CBD. There are plans to complete trail links to provide further connectivity along Kororoit Creek. Currently a bicycle/walking trail runs up the west side of Kororoit Creek.

1.3 Key impacts, systems, values and major drivers

Three main subsystems influence environmental aspects of the integrated urban water system within the Brooklyn Industrial Precinct:

1. The water supply, stormwater, sewerage and runoff system within the precinct.
2. Kororoit Creek and catchment that adjoins the precinct on its western edge. Note that the precinct also flows into Stony Creek but the contribution is minor.
3. The airshed carrying dust and aerosol particles originating within the precinct.

The role of water in supporting the operations of a number of businesses within the precinct is described in the E2D Report (Browne and Brookes, 2014). This report is mainly concerned with the third subsystem – the airshed itself and how it interacts with the other two subsystems.

Because this project aims to develop solutions within a vision of integrated water cycle management, we have developed an impact-response framework that links the major drivers, impacts, values and governance within the Brooklyn Industrial Precinct. This is described in detail in the next section. A whole system analysis has been carried out because multiple interactions and feedbacks within the system are too complex for a simple cause, effect and response model.

Important definitions for this framework are:

- Drivers – variables that act on a system producing one or more effects. Here, only physical drivers are assessed; underlying motivations (e.g., profit, health or sustainability) are not considered as drivers.
- Impacts – the effects produced by drivers. For example, land-use, transport and weather are the drivers of airborne dust and particles within the precinct.
- Shapers – variables that influence system sensitivity to impacts. For example, transport is the major source of dust and aerosols from the site, but processes that make sediment available

such as land use and soil moisture, shape the degree of system response. Some variables, such as wind, can be both drivers and shapers.

- Values – goods, services or qualities that are sought after or whose loss would be regretted. Values can range from business income through to catchment condition, water quality and clean air. Institutional values are also important. These include the profit motive of business, productivity and community health and connectedness. Different institutions have different values, which can sometimes be in conflict.
- Governance – the institutions and rules that have influence over the system at any point from drivers through to shapers and outcomes. Governance is a key aspect of risk management but it also influences institutional norms and activities. These, in turn, affect shaping variables and values. The governance of integrated urban water management is complex because of the many institutions involved.

The next section describes the framework, before moving onto the details of the airshed subsystem.

1.4 Impact-response framework

Impact-response frameworks are useful for teasing out complex system interactions. Such frameworks relate a wide range of biophysical variables to activities, linking the scientific understanding of a system to its purpose and use.

The impact-response framework developed for this project contains the three subsystems mentioned in the previous section, along with a section that contains community, industry and government factors (horizontal axis of Figure 1). Biophysical variables are listed down the vertical axis, activities and groups are listed on the horizontal axis. Any cell where a variable affects an activity or group is marked. This helps determine which variables are most influential in a system, but will not necessarily pick up the most important impacts.

Drivers and responses are mapped by including all variables, activities and groups on a single axis repeated on both the horizontal and vertical. The vertical axis is the forcing axis and the horizontal axis is the dependency axis. Each variable on the vertical axis is checked with all variables on the horizontal axis and if any are affected, the cell is ticked. In this case, there are 54 variables, so the resulting matrix contains almost three thousand decisions. These are totalled on each axis.

The strongest drivers (most influential variables) score highly on the vertical axis and the most affected variables score highly onto the horizontal axis. These can be organized visually on a chart and grouped into four quadrants:

- Driving variables act on the system from outside and are not greatly affected by interactions within the system.
- Relay variables are strong drivers but are also affected by what goes on the system. These often involve feedbacks that can amplify impacts within the system.
- Passive variables have only a few interactions within the system and are not very influenced by it. These may be important, but their role is usually quite straightforward.
- Dependent variables are greatly affected by what goes on in the system. These are generally the most valued variables because they relate to outputs and outcomes.

	Water Supply, Stormwater and Runoff									Kororoit Creek & Catchment							Airshed				Community and Industry										
BIOPHYSICAL VARIABLES / ACTIVITIES MATRIX	Potable water supply	Industrial water use	Irrigation	Borewater	Trucked water	On-site storage	Storm water management	Sewerage management	Site infrastructure design	Catchment management	Creek management	Water quality	Flood levels	Sediment supply	Land cover	Recreational uses	Visible dust (AQ perception)	PM10 Health limits	PM2.5 Health limits	Odours	Industry	Community	Local government	Government agencies	Preschools & schools	Airshed amenity (clean air)	Occup. health and safety	Population health	Outdoor comfort levels	Recreational access	Transport	Business operations	
Temperature (av.)			1					1	1			1				1				1								1			1	8
Temperature (daily max.)		1	1		1				1							1	1	1	1	1	1	1		1	1	1	1	1	1		1	19
Evaporation (daily)	1		1		1	1			1	1	1	1		1	1		1	1	1		1		1			1			1			17
Humidity																	1	1	1	1						1	1	1	1				8
Rainfall (annual total)	1		1	1	1	1	1	1	1	1	1	1	1	1	1											1	1						14
Rainfall (daily)		1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1		1	1				1	1	1	24
Rainfall intensity						1	1	1	1	1	1	1	1	1			1	1	1		1		1		1	1	1			1	1	1	20
Wind speed					1				1								1	1	1	1						1	1	1	1			1	11
Wind direction					1									1			1	1	1	1						1	1	1	1				10
Runoff			1		1	1	1	1	1	1	1	1	1	1	1	1					1		1	1					1				17
Peak runoff						1	1	1	1	1	1	1	1	1							1					1			1			1	14
Groundwater		1	1	1				1		1	1	1									1			1								1	10
Streamflow									1	1	1	1	1	1																			6
Flooding												1	1		1	1					1	1	1	1		1			1			1	11
Drought	1	1	1	1	1	1		1	1	1	1	1		1	1		1	1	1		1	1	1	1	1	1		1	1			1	25
Fire									1	1	1			1	1	1		1	1		1		1	1		1	1	1		1	1	1	17
Soil moisture			1		1		1			1	1			1	1		1	1	1			1	1										12
Land cover (vegetative)							1			1	1	1		1	1	1	1	1	1		1	1	1		1				1	1			16
Available sediment							1		1	1	1	1		1	1		1	1	1		1					1					1		13
Dust (visible)																	1	1	1		1	1	1	1	1	1	1	1	1		1	1	14
PM10																		1	1		1	1	1	1	1	1	1						10
PM2.5																		1	1		1	1	1	1	1	1	1						10
	3	4	9	3	9	7	8	8	13	13	13	13	7	13	11	7	12	15	15	6	14	8	13	8	8	13	11	9	9	8	5	11	

Figure 1. Impacts-response matrix for the urban water system with respect to the Brooklyn Industrial Precinct.

Figure 2 shows the forcing-dependency chart for the integrated urban water cycle in the Brooklyn Industrial Precinct. The forcing variables in the top left quadrant are weather-related variables that influence the water cycle. Water supply variables are largely defined as passive because they are mostly influenced by off-site forces and are little affected by what happens onsite. Important relay variables include site infrastructure design, land use and land cover and key institutions such as industry and government. Dependent variables include water quality, population health and occupational health and safety. These are generally environmental and community values linked to clean water and air.

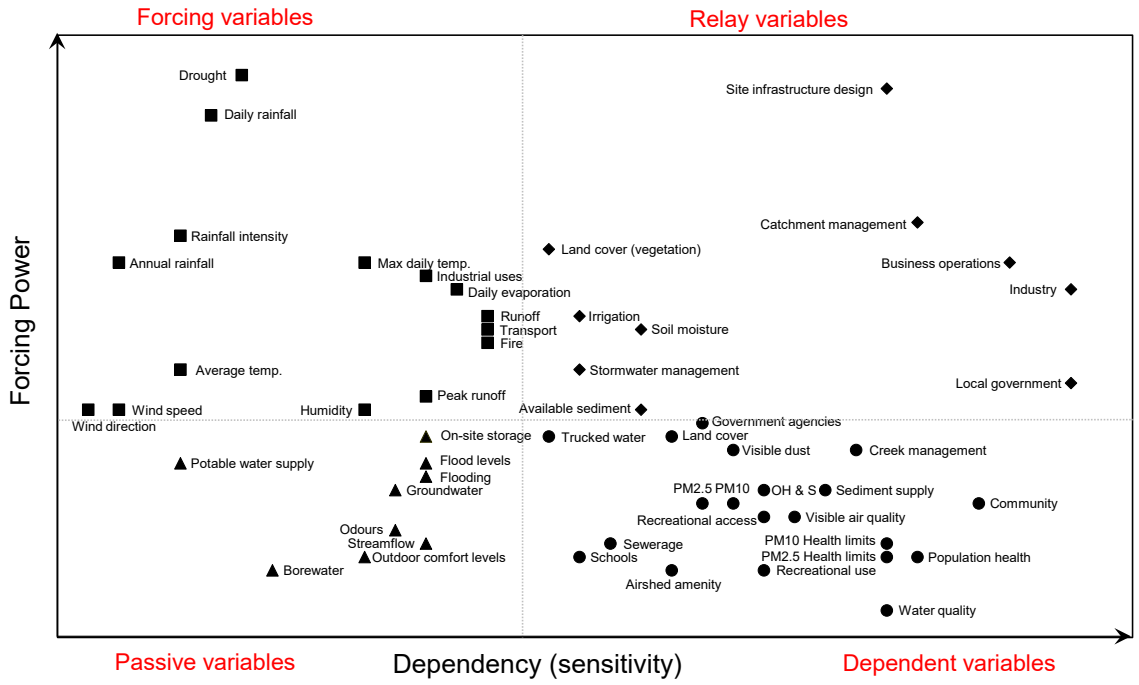


Figure 2. Forcing-dependency chart developed from a survey of interactions affecting the integrated urban water cycle in the Brooklyn Industrial Precinct.

1.4.1 Airshed subsystem map

The airshed subsystem is mapped in Figure 3, showing drivers (green arrows), impacts (blue arrows, shapers (green arrows) and governance (yellow arrows). This model shows a broad range of variables known to influence the generation, dispersal and impacts of dust and aerosols from the Brooklyn Industrial Precinct. Figure 3 incorporates all key variables; minor ones have been omitted.

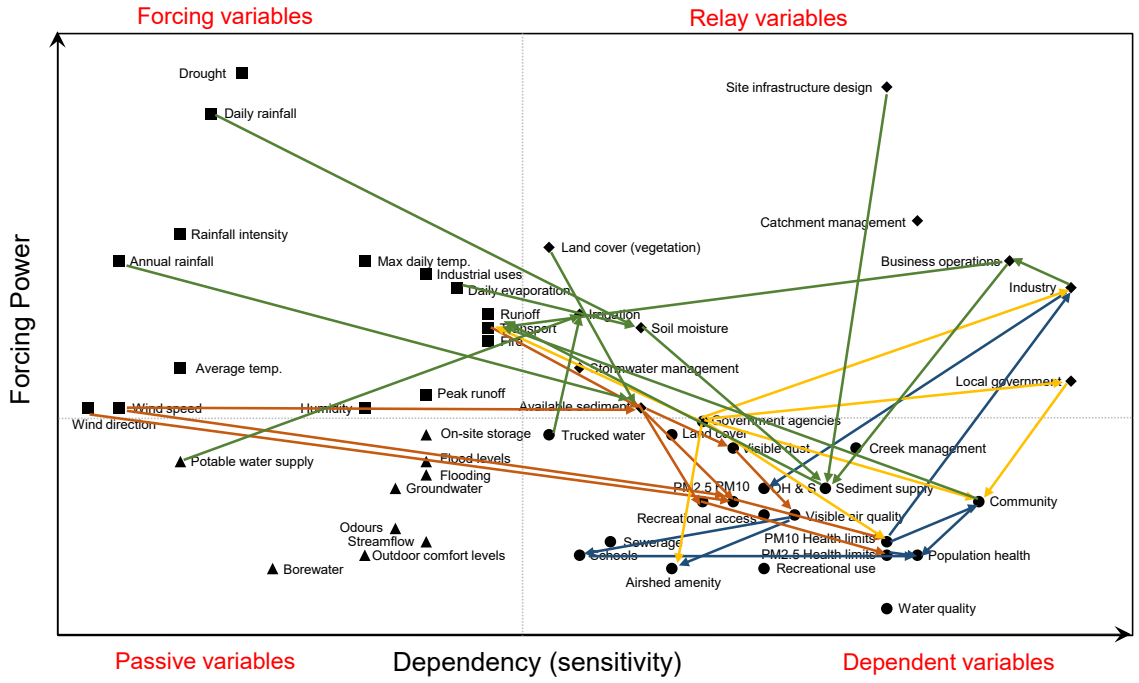


Figure 3. Airshed interaction model for the Brooklyn Industrial Precinct.

Understanding the airshed subsystem and its health effects requires data from a wide range of sources, covering important all aspects. Table 1 shows the drivers, shapers, impacts, governance and outcomes from Figure 3. To understand the outcomes and values affected in the final column, we have analysed the first three columns and identify the opportunities for governance in the fourth column. This analysis is presented in the next section.

Table 1. Drivers, shapers, impacts, governance and outcomes taken from Figure 3.

Drivers	Shapers	Impacts	Governance	Outcomes
Wind speed	Daily rainfall	PM2.5	Industry	PM10 health limits
Wind direction	Annual rainfall	PM10	Community	PM2.5 health limits
Transport	Daily evaporation	Visible dust	Local government	Airshed amenity
Available sediment	Land cover (vegetative)	Community exposure	Government bodies	Population health
	Trucked water	Industry exposure		OH & S
	Soil moisture	Schools exposure		
	Site infrastructure design			
	Sediment supply			
	Business operations			
	Irrigation			

2 Subsystems and values

The impact-response framework describes three interacting systems related to the integrated urban water cycle within the Brooklyn Industrial Precinct:

1. The on-site urban water system.
2. The Kororoit Creek catchment.
3. The airshed linked to the precinct.

2.1 Brooklyn Industrial Precinct urban water system

The urban water system within the Brooklyn Industrial Precinct consists of water supply, stormwater and sewerage systems, but also includes on-site rainfall, runoff and groundwater. This is discussed in detail in the E2D Report (Browne and Brookes, 2014) and briefly summarized here:

- The most recent water use onsite for year 2012–13 was about 1,500 ML. Most of that water is consumed by only a few users with the top ten using 95% and the top three 85% (Browne and Brookes, 2014).
- The wide range of businesses and land-uses on site mean that water use, stormwater management and sewerage and trade waste disposal are very diverse. Water is a high input cost for a number of businesses and water management for others.
- Water is used for dust suppression by a range of businesses and also by Brimbank City Council. Most water used is potable mains water, but some water is collected onsite and re-used or sourced from groundwater. Browne and Brookes (2014) estimate that about 136 ML/yr is used by landfill sites and that another 1.7 ML/yr is sourced from hydrants. Water use for dust suppression can be a significant cost for some businesses.
- Sewerage is estimated as being almost 1,400 ML/yr and is mostly composed of trade waste, providing opportunities for treatment and re-use.
- The site water balance reveals stormwater runoff of 1,045 ML/yr, about five times greater than estimated natural runoff. It carries an estimated 150,000 kg suspended solids, almost 200 kg of phosphorus and about 1,500 kg of nitrogen. The latter are mainly of natural atmospheric (cyclical origin), but the higher proportion of runoff into an already polluted system, mean that loads in the adjacent Kororoit and Stony Creeks are too high.

Land-use and industrial activities are extremely important for both water and dust issues. The main issues are summarized:

- Past activities include extensive quarrying and the resulting depressions have been used for landfill. The last of these is still active, but older quarry landfills along the creek have been capped and are in the process of stabilization. Most of these landfills are 5–15 m above the surrounding land surface. Sediments are therefore exposed to the elements, especially if they are not stabilized by vegetation or other means.
- Many sorting, recycling and container yards are unsealed, leading to dust production from vehicular traffic. Other sites also have dust-producing activities, such as heavy recycling.
- The lack of site drainage and associated services along with a history of activity and abandonment has led to limited water management infrastructure within the precinct. Uncontrolled drainage allows an estimate 150 tonnes of suspended solids into waterways every year (Browne and Brookes, 2014).
- Roads within the precinct reflect this lack of development. Internal roads, such as Jones and Bunting Road are poorly sealed or unsealed, while major through roads such as McDonald

and Somerville roads have bare verges above gutter height and accumulate sediments of road verges. Plans to address both these issues are underway.
- Landfill has encroached onto the banks of the Kororoit Creek, in places altering the creek profile and allowing further sediment into the creek, preventing access and hampering remediation efforts.

2.2 Kororoit Creek and catchment

Kororoit Creek is approximately 80 km long and flows from north of Sunbury through the western suburbs to Port Phillip Bay in Altona. For most of its length it flows through the western basalt plains and is an incised stream with rocky escarpments of low relief. Brooklyn is situated on the lower reaches of the creek. Creekside lot boundaries have been poorly managed in the past (see above), altering its profile.

Of particular importance, is the Kororoit Creek Regional Strategy 2005–2030, a long-term strategy to protect, manage and improve access to a 40km stretch of Kororoit Creek from Toolern Vale, north east of Melton to Altona (DSE, 2006). Actions significant for Brooklyn include a bicycle/walking path on the west side of the creek, revegetation and improvements in water quality. Water sensitive urban design is an action recommended to improve water quality.

The direct benefits of improved creek margins include:
- Increase in wildlife (birds, insects, reptiles)
- Improvement in aquatic environment – plants and animals
- Interception of pollutants
- Stabilisation of sediment
- Marginal increases in water quality
- Cooler environment due to greater transpiration
- Genetic and biodiversity is increased if local vegetation is used
- Sequestration of CO_2

Most of these benefits are marginal and will be small. Some, such as the improvements in water quality seen within a large catchment with multiple effects are subject to threshold effects. For example, good water quality requires the interception of about 67–80% of direct runoff, therefore the full benefit of marginal changes are not seen until broadscale catchment restoration is undertaken. However, if good water quality becomes a management target, the omission of high-impact areas like Brooklyn would make such a task very difficult, if not impossible.

Widespread regional cooling effects also require large-scale urban forestry and wetlands. Having a tree canopy and available moisture wherever possible will ameliorate environmental extremes.

The Federation Trail, running through the south-east corner of the precinct, is the principal linear recreation and non-motorised transport link in Melbourne's West. Linear trails have amongst the highest value of open space recreation areas, and the same argument can be made as made for water quality in Kororoit Creek: its greatest value is in its connectedness, so the loss of even a small part degrades the whole significantly.

2.3 Brooklyn Industrial Precinct airshed

The history of the Brooklyn Industrial Precinct as a site for quarrying, heavy industry and meat processing, landfill and recycling has led to a longstanding legacy of dust and odour. Efforts to clean up both have only recently gained momentum over the past seven or so years, with the Brooklyn Community Reference Group Agreed Terms of Reference (Brooklyn Community Reference Group, 2007). These terms were agreed to by local community groups, industry representatives, local government and EPA Victoria. Considerable efforts have been made in managing both odours and dust, with varying degrees of success. Although gains have been made, especially with odours, further progress is needed.

This section summarizes air pollution in form of dust, PM10 and PM2.5 particles and odours originating from the precinct, covering its likely origin, causal factors, timing and risk. This information feeds into the economic assessments in Section 5. The analysis and summary comes from work undertaken or commissioned by the Victorian EPA and analyses carried out for this project. Data was kindly provided by the EPA and Brimbank City Council.

Dust covers all forms of airborne aerosols ranging from visible to invisible. PM10 and PM2.5 are invisible aerosols 10 and 2.5 nanometres in diameter respectively. All these aerosols are considered harmful, but the smaller the particle, the greater danger it poses, largely because smaller particles cannot be removed from the lungs by normal bodily processes. Chemical compositions show the dust from the BIP is largely mineral, and is most likely derived from the soil (EPA, pers. comm.).

Table 2. State Environment Protection Policy limits for pollutants relevant to the study.

Pollutant	Daily limit	Annual limit	Statutory limit	Notes
Visibility	20 km		3 days per year	Fine particle scattering
Dust				Pursued from complaints data
PM10	50 µg/m^3		5 days per year	
PM2.5	25 µg/m^3	8 µg/m^3		Advisory levels only
Odour				Pursued from complaints data

Hourly data for PM10, air temperature, light scattering, wind direction and speed was provided by the EPA for four monitoring stations: Brooklyn, Brooklyn School, Footscray and West Sunshine (Figure 4). Monitoring commenced in November 2009 and carries through to August 2013. Additional daily data for PM10 adjusted for temperature was provided, along with calculations for PM2.5 for twelve months in 2010–2011. The Brooklyn and Sunshine West monitoring stations were opened to monitor pollution from the precinct as a result of the Brooklyn Community Reference Group Memorandum of Understanding (Brooklyn Community Reference Group, 2007). The Sunshine West station was run from September 2010 to December 2011 and only recorded one day of poor air quality in that time.

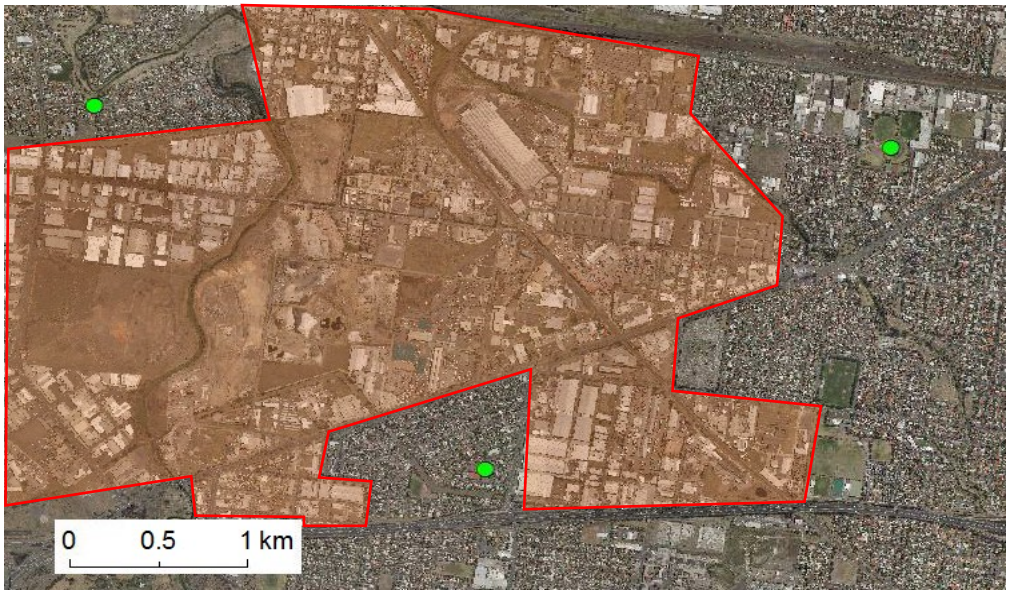


Figure 4. Brooklyn Industrial Precinct showing industrial areas and three EPA air quality monitoring stations: Sunshine West (upper left), Footscray (upper right) and Brooklyn (lower centre; source: EPA).

Analyses carried out by the EPA show that roads and traffic are the main sources for aerosols (Sichlau and Folker, 2012a, b) but weather directs where the aerosols travel to and how long they persist. We carried out in-depth statistical analyses of the data, confirming the EPA's major findings and adding more detail on the timing and duration of events. While it is difficult to determine the full spatial extent of pollution events, their timing and duration is now much better known.

2.3.1 Spatial extent

It is difficult to establish how far the Brooklyn Industrial Precinct airshed extends; therefore, the potential reach of pollution from the site has been estimated from wind data, complaints data from the EPA and short-term monitoring at other sites in the vicinity.

Winds at the Brooklyn combined and Footscray EPA observation sites show that the most common wind directions are northerlies, southerlies and westerlies in that order (Figure 5). Note that when the spider chart points to the north, the wind is coming from the north, opposite to the direction the chart is pointing to. The wind charts in Figure 5 shows that for Brooklyn to affect the site, winds would have to be coming from the south-east and these are quite uncommon in the area. For example average hourly PM10 at the Sunshine West site was 16.7 µg/m^3 over that period, whereas for Brooklyn, it was 22.0 µg/m^3.

Another way to ascertain the spatial extent of the area affected is to track dust and odour complaints. Figure 6 shows six-year (2008–2013) spatial distribution of complaints about odour and dust. They show that odour, which are volatile organic chemicals are spread quite widely to the south and south-east. It is often difficult to ascertain the source of dust and odours, which can either be local or more widespread if not specifically identified. Odour complaints are much more dispersed than dust, which is to be expected. However, it is not possible to use this data to estimate the full extent of dust and aerosol plumes originating in the precinct.

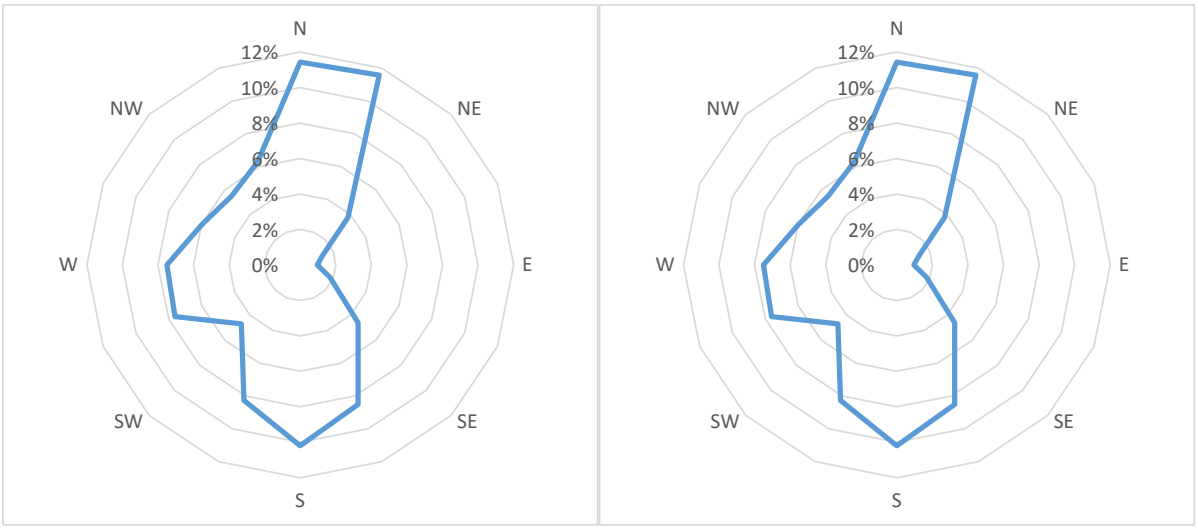


Figure 5. Annual wind direction at the Brooklyn combined monitoring site (left) and Footscray (right) measured on an hourly basis.

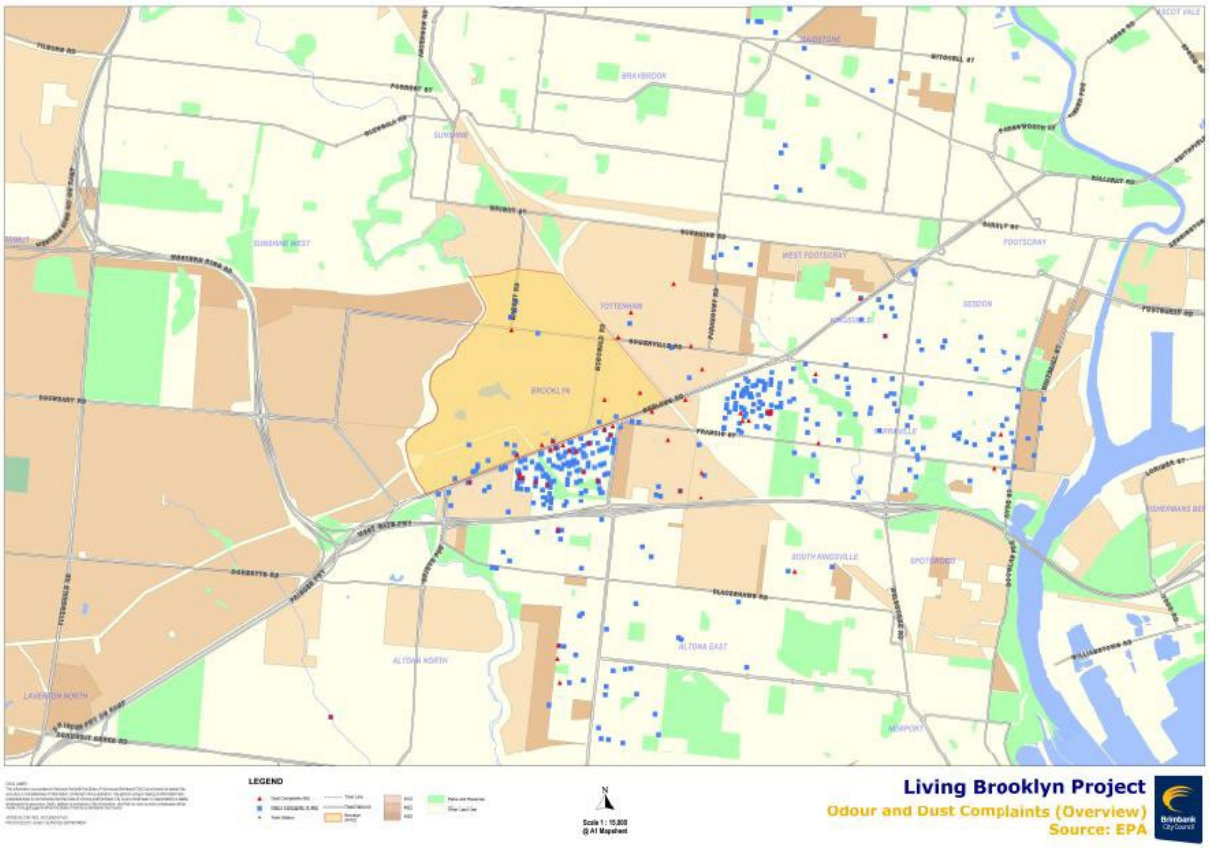


Figure 6. Data map from EPA, showing six-year (2008-2013) spatial distribution of complaints about odour (blue) and dust (red) plotted on site map. Individual complaints from each were tallied for each sub-area to determine rough spatial distribution of odour.

Lastly, temporary monitoring projects have identified peaks in poor air quality that can be attributed to the precinct, or not, in some cases. Monitoring on the Westgate Freeway in 2004, clearly identifies peaks in poor air quality that must be derived from Brooklyn, because they are shown along with Footscray and Alphington data that show the same movements but not the peaks (EPA, 2005). The first year of the Brooklyn Monitoring Project shows peaks of poor air quality in an undisclosed location

in Yarraville (EPA, 2011), but other monitoring on Francis Street in the same suburb does not (EPA, 2013b). This latter monitoring has taken place near the eastern end of Francis Street, showing that if any poor quality air mass from Brooklyn reaches that far, it does so only occasionally.

Another line of evidence are modelled levels of average daily ground level PM10 calculated for the EPA (Sichlau and Folker, 2012) and shown in Figure 7. This shows high level of PM10 that will affect workers onsite and adjacent resident populations, particularly to the south.

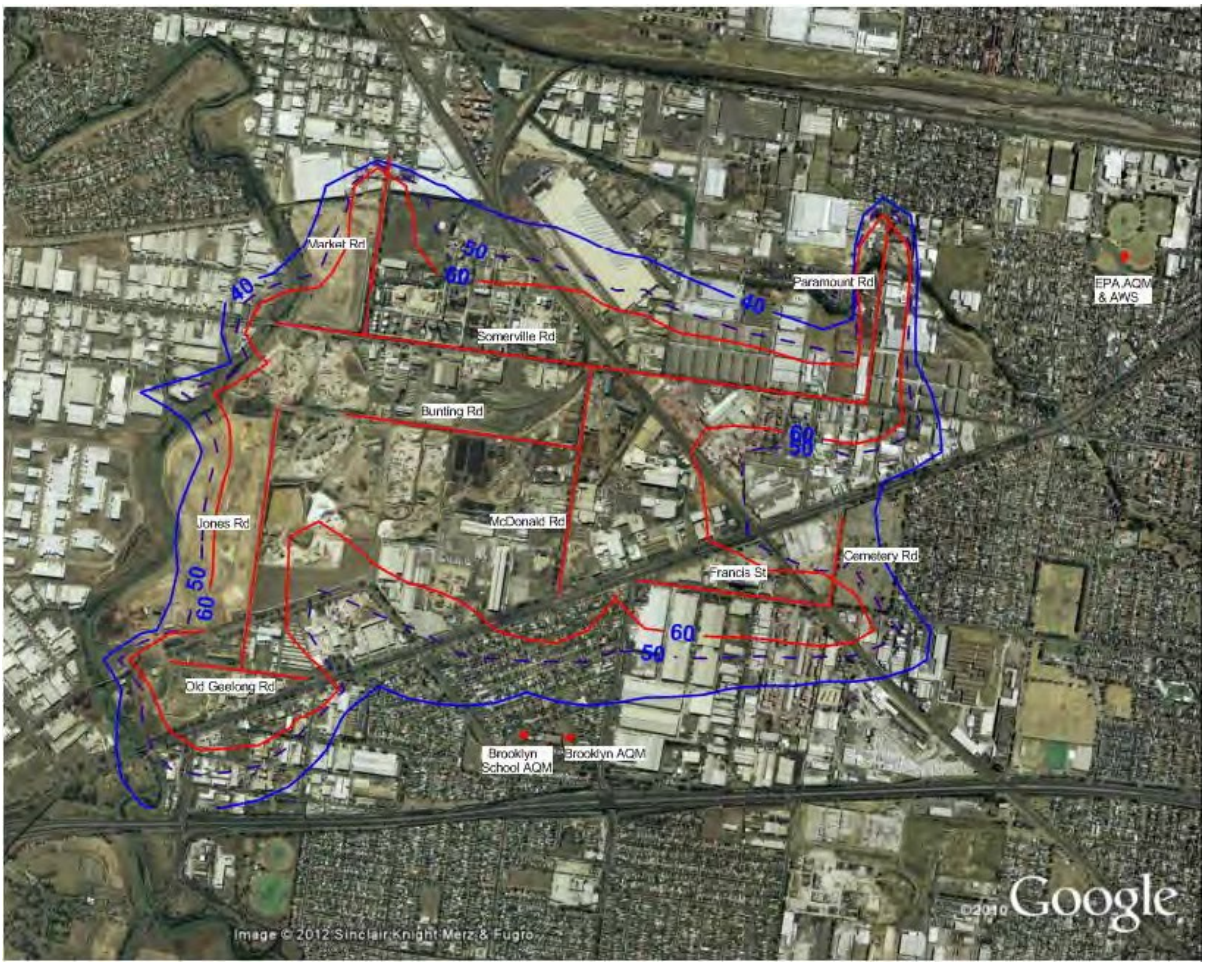


Figure 7. A contour plot of the predicted 24-hour average ground level PM10 concentration associated with road dust emissions, excluding the influence of background PM10 levels and emission from other sources within the industrial precinct (Sichlau and Folker, 2012).

2.3.2 Exposure

The resulting estimation of the airshed was then used to estimate population exposure to air pollution that could be represented by air quality from the Brooklyn and Footscray monitoring stations. These are illustrated in the maps by grey lines, with each boundary demarcating a single residential mesh block from the Australian Bureau of Statistics (ABS) National Census 2011 (industrial and parkland mesh blocks, containing no population, are also illustrated). Figure 8 represents the area covered by the Brooklyn monitoring station and Figure 9 represents the area covered by the Footscray monitoring station. Figure 10 represents an area affected by particles carried south of the Westgate Freeway, to Altona North. These areas, nominated 1–7 are shown in red lines.



Figure 8. Residential population to the South of Brooklyn Industrial Precinct, showing residential, industrial, and parkland mesh blocks.



Figure 9. Residential population to the East of Brooklyn Industrial Precinct showing residential, industrial and parkland mesh blocks.

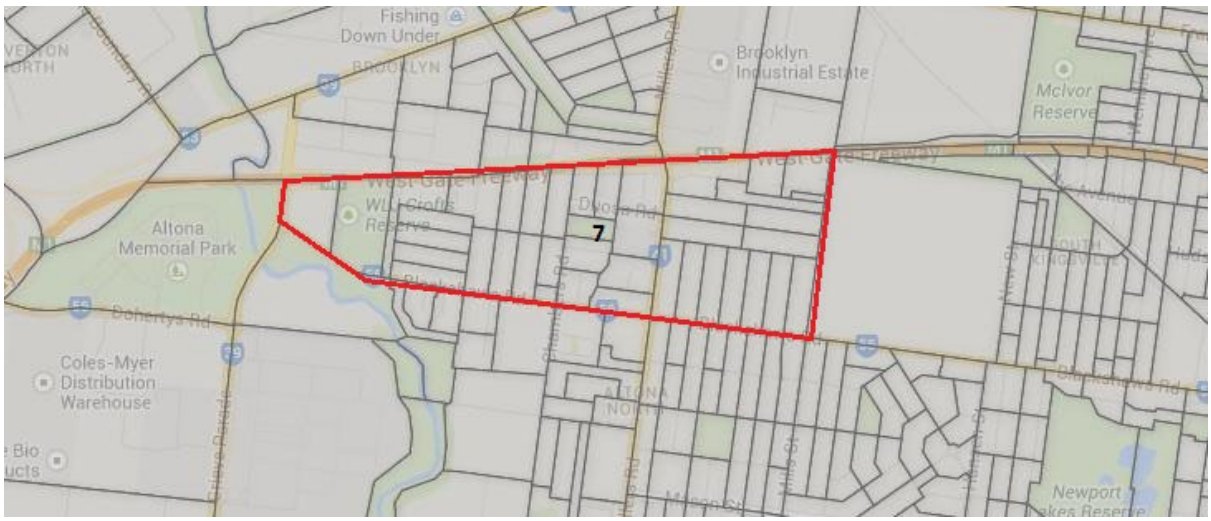


Figure 10. Residential population to the South of Brooklyn Industrial Precinct and Westgate Freeway, showing residential, industrial and parkland mesh blocks.

Data from the Australian Bureau of Statistics (ABS) National Census 2011 was used to calculate the population likely to be affected by dust and odour. The census date was 9th August 2011.

Assuming these boundaries, a total population of 17,684 residents are affected by the Brooklyn airshed. For modelling the impact of dust (PM10 and PM2.5 particles), those residents in Areas 1–5 and 7 were assessed based on figures from the EPA Brooklyn air quality monitoring station, while those in Area 6 were assessed based on figures from the EPA Footscray monitoring station. Note that this population includes the residential houses around the Brooklyn Industrial Precinct, but does not include day workers within the Precinct.

Table 3. Residential areas with total ABS National Census (2011) Mesh Blocks, household, and population counts.

Area	Boundaries	ABS Mesh Blocks	Households	Population
1	Geelong Rd, Millers Rd, West Gate Fwy	26	797	1,637
2	Francis St (Docklands Hwy), Williamstown Rd, Westgate Fwy, Millers Rd	33	677	1,574
3	Geelong Rd (Princes Hwy), Roberts St, Francis St (Docklands Hwy)	20	637	1,470
4	Somerville Rd, Williamstown Rd, Francis St, Roberts St	37	1,256	3,112
5	Geelong Rd (Princes Hwy), Williamstown Rd, Somerville Rd,	46	1,694	3,525
6	Sunshine Rd, Geelong Rd (Princes Hwy), Somerville Rd, Paramount Rd	49	1,450	3,116
7	Westgate Fwy, Kyle Rd, Blackshaws Rd, Grieve Pde	41	1,358	3,250
TOTAL		211	7,869	17,684

3 Air quality assessment

3.1 PM10

PM10 is the variable with the most comprehensive data (from measurement through to health impacts) so receives the greatest scrutiny. Compliance limits for the EPA is 5 days of PM10 greater than 50 micrograms per cubic metre (µg/m^3) of air per year (Table 2). Throughout this report, this limit is referred to as PM10 >50. All hourly PM10 data supplied were adjusted for temperature using the EPA corrections when temperature is less than 15°C:

$$\text{If } t < 15,\ PM10_t = PM10 \times (1 + 0.04(15-t))$$

The major focus is on the Brooklyn station in the centre south of the area. Footscray experiences pollution events similar to those elsewhere in Melbourne, except for a few days per year. Sunshine West has 15 month's data from 2010–2011. Brooklyn is a combination of Brooklyn School (2010–11) and Brooklyn (2010–13). Brooklyn School readings are 9% higher than Brooklyn, but no adjustment was made when combining the time series.

For PM10, Brooklyn averages 28 days greater than the 50 µg/m^3 limit per year, Footscray averages 3 days per year and Sunshine West had one exceedance during the period it was open. Although there have been changes over the period of record, four years is too brief to establish any management improvements over time. Lower days of exceedance at Brooklyn in 2011 (Table 4) may be due to the very wet year, and indicate the potential of moisture for stabilizing sources of dust and aerosols. Rainfall at Laverton RAAF, 7 km to the west was 767 mm for 2011, 613 mm in 2010 (mostly in the latter part of the year) and 466 mm and 494 mm in 2012 and 2013 respectively.

A weather adjustment could potentially separate the influence of weather from site and management effects. Possible variables that could be used include wind direction (degrees from preferred direction 11 degrees E at Brooklyn), air temperature, days since rain or wetness index, and air stability.

Table 4. Total PM10 >50 monitored at EPA stations (EPA data).

Year	Brooklyn combined	Footscray	Sunshine West
2009 (2 months)	10	2	0
2010	32	4	0
2011	13	0	1
2012	30	3	0
2013 (8 months)	21	1	0

3.1.1 Wind direction and PM10

Analysis of PM10 hourly readings at the Brooklyn combined site shows the strong influence of northerly winds on PM10 concentrations. Overwhelmingly, the greatest number of hourly exceedances is associated with northerly and north westerly winds. Figure 10a shows the annual average hours of exceedance of 50 µg/m^3 PM10 as a function of wind direction. Also shown is the proportion of time when the wind is blowing from a direction that PM10 >50 is exceeded (Figure 10b). 82% of exceedances occur when the wind is within the range of 292.5 to 45 degrees (NW to

NE). The likelihood of PM10 >50 when the wind is in this quarter is 21%, but this figure can be much higher, depending on the time of day.

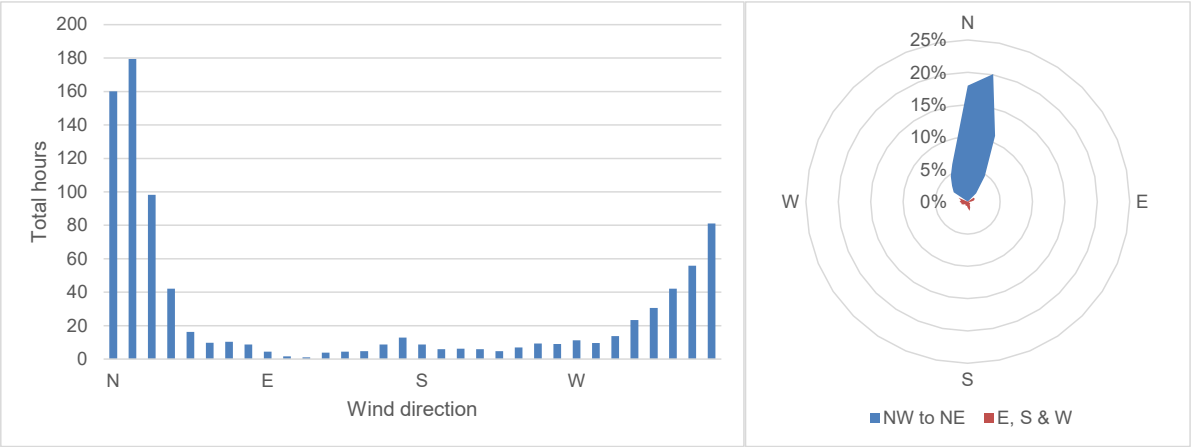


Figure 11. (a) Annual hours of exceedance of PM10 greater than 50 micrograms per cubic metre (μgm^{-3}) of air at the combined Brooklyn monitoring station 2009–2013; (b) Percentage of total annual hours of exceedance from a given wind direction, divided into NW to NE quadrant and the three E, S and W quadrants combined.

Footscray, to the east of the precinct shows much lower levels of exceedance, which are mainly influenced by westerly winds (Figure 11a and b).

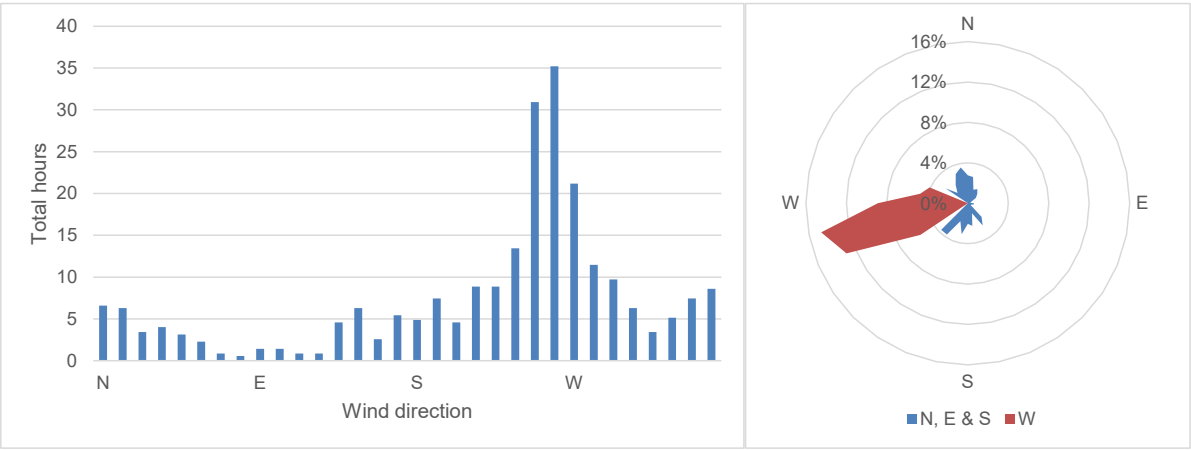


Figure 12. (a) Annual hours of exceedance of PM10 greater than 50 micrograms per cubic metre (μgm^{-3}) of air at the Footscray monitoring station 2009–2013; (b) Percentage of total annual hours of exceedance from a given wind direction, divided into NW to NE quadrant and the three E, S and W quadrants combined.

Wind speed is an important factor, but not as significant as direction. The correlation between wind speed and PM10 levels is positive; i.e., higher wind speeds are associated with higher PM10, but low wind speeds are much more common. Figure 12 shows that although PM10 >50 is more common at low wind speeds these exceedances occur less than 20% of the time at those wind speeds, whereas high wind speeds are much less common but are highly associated with poor air quality. PM10 >50 shows no clear seasonality, occurring at any time of the year, but is correlated with daily temperature (i.e., occurs more often on warm days than cool days). This may in part be a function of wind direction, given that northerly winds are generally warmer, but is also because dust is more mobile in warm conditions.

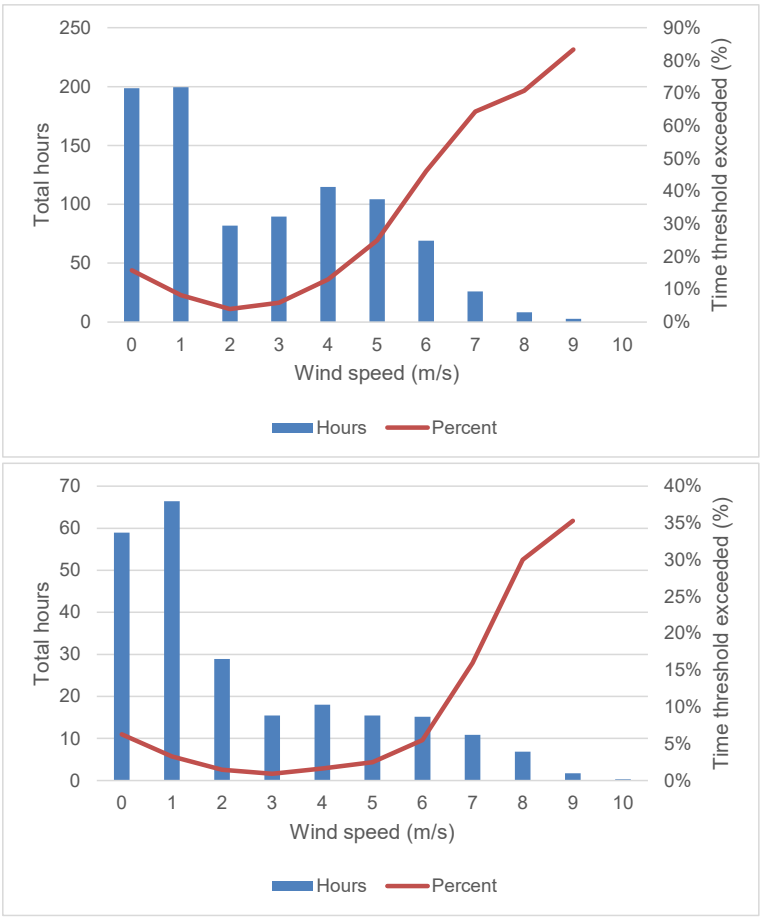


Figure 13. Hours per year of PM10 >50 at specific wind speeds (blue bars) with the percentage of time air quality is exceeded at that wind speed (red line) for Brooklyn (upper) and Footscray (lower).

3.1.2 Timing of PM10 events

Time of day is very important as shown by the rate of PM10 >50 for each hour of the day (Figure 13). Until 5am, exceedances are low (<4%) but rapidly increase to 30% between 8–9 am. On this basis, three out of every ten days will exceed PM >50 at that time. This probability declines at a fairly constant rate until 6 pm, where rates of <5% exceedance are maintained overnight. If winds are blowing from the north quarter (NW to NE) these likelihoods are much higher. For example, the likelihood of PM10 >50 is 62% at 9 am if winds are from the northern quarter. At midday, this is probability is 42%, a level sustained to 3 pm. By 6 pm, even if the winds are still from the north, the likelihood of exceeding PM10 >50 falls to 11%. This is important information for vulnerable people in exposed areas during the day. For example, if winds are from the north, outdoor exercise in the evenings will be much more beneficial than the mornings.

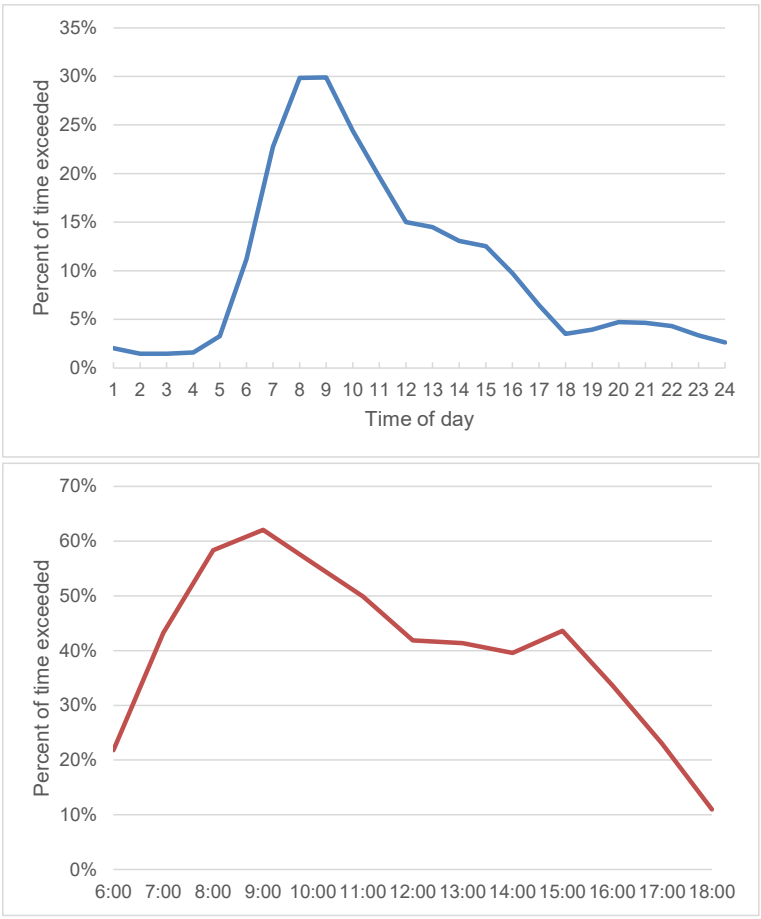


Figure 14. Percent exceedance of PM10 greater than 50 micrograms per cubic metre (μgm^{-3}) on an hourly basis at Brooklyn (upper) and when winds are blowing from the north quarter (NW to NE).

The story from Footscray is less dramatic. If winds are from the west, the likelihood of PM10 >50 being reached is 20% at 8 am, or one in five. This decreases quite quickly, reaching 7% by midday.

Three related atmospheric processes combine to produce the day–night pattern observed at Brooklyn: wind speed, wind direction and atmospheric stability. During the day wind speed increases from a night-time average of less than 2 ms^{-1} to a peak of over 4 ms^{-1} in the afternoon (Figure 14). Wind direction is also from the northern quarter half the time at 6 am but shifts to other quarters in the late afternoon, with northerly winds occurring only one quarter of the time (Figure 15). Atmospheric stability is linked to the atmospheric boundary layer, which acts as a barrier for rising air. At night the boundary layer is relatively low, but during the day rises with increasing temperature causing greater atmospheric instability. This will help disperse particulates held in atmospheric plumes. Occasionally, inversions occur, where cooler air is beneath warmer air – at such time concentrations may increase during the day with even light northerly winds. These events are associated with high pollution events across the larger Melbourne area, so are not localised to Brooklyn, but may be exacerbated in the Brooklyn area under high traffic volumes.

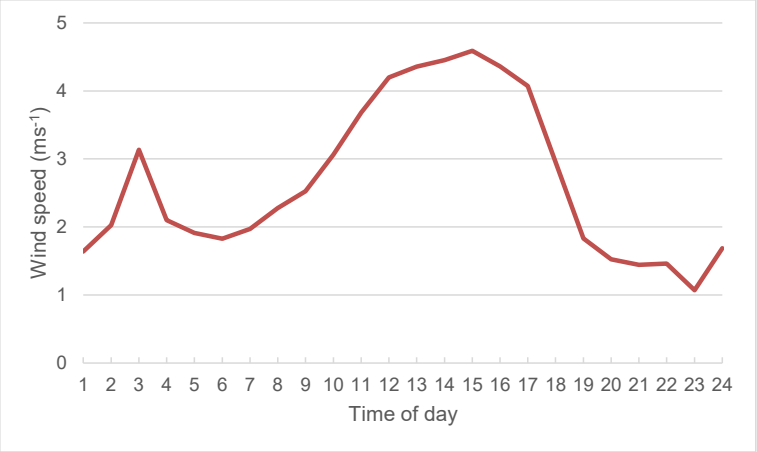


Figure 15. Average wind speed during the day at the Brooklyn monitoring station.

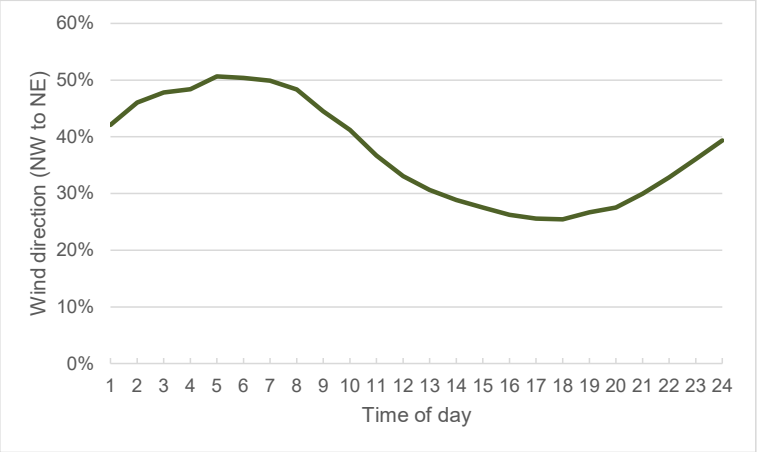


Figure 16. Percent of the time winds are from the north quarter (NW to NE) during the day at the Brooklyn monitoring station.

3.1.3 Traffic and PM10 production

Traffic monitoring was undertaken for Brimbank City Council on Jones and Bunting Roads, one of the BIP's busiest roads for two weeks in March–April 2011. Superimposed on the PM10 >50 data, are average daily traffic counts for both roads over two weeks (Figure 16). The increase in PM10 >50 follows the build-up of light vehicle traffic but is not sustained later in the day, as noted earlier.

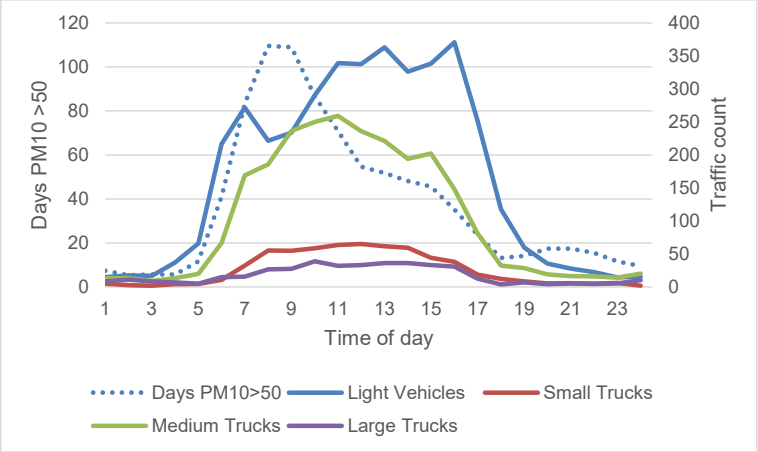


Figure 17. Frequency of PM >50 in days per year at Brooklyn plotted against time of day with average hourly traffic counts from a two-week traffic survey of Jones and Bunting Roads.

When plotted against all traffic, the relationship between vehicle counts and PM10 levels is striking, showing the string relationship between vehicle movement on Brooklyn's roads and aerosol production (Figure 17). These relationships are similar for Footscray, except that hourly levels of exceedance peak at 25 days per year of PM10 >50 when winds are from the west. The rate of decline during the morning is also faster.

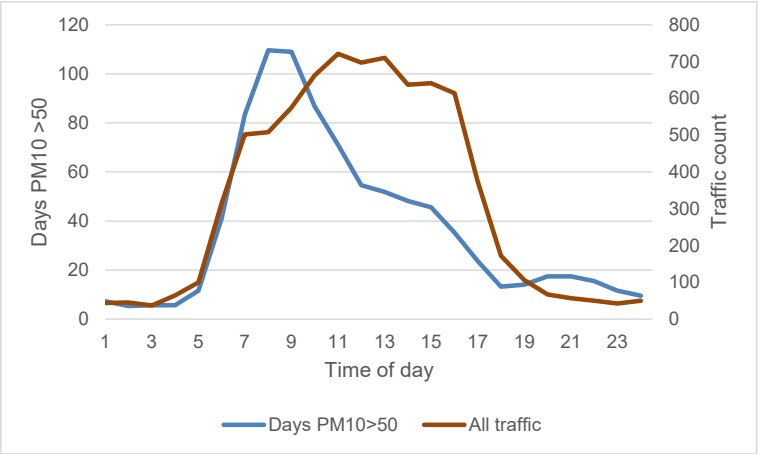


Figure 18. Frequency of PM10 >50 in days per year at Brooklyn plotted against time of day with average hourly traffic counts from a two-week traffic survey of Jones and Bunting Roads.

Day of the week is also important for both air quality and traffic volumes. Only 1.4% of Sundays see the PM10 threshold breached, whereas this occurs on about 10% of all weekdays (Table 5). The proportion of breaches correlates closely with traffic volume (0.91), high during weekdays, moderate on Saturday and low on Sunday. Interestingly, traffic volumes are high on Monday but PM10 >50 is not as high, suggesting the potential role of traffic in transporting dust onto roads.

Table 5. Incidence of hourly average PM10 >50 on a particular day (Column 1), as a proportion the weekly total (Column 2) and traffic volume as a proportion of the weekly total (Column 3).

Weekday	PM >50 on the day	PM >50 of all days	Traffic volume
Sunday	1.4%	1.9%	1.4%
Monday	9.4%	14.5%	20.3%
Tuesday	12.8%	20.3%	19.5%
Wednesday	12.9%	20.6%	17.6%
Thursday	12.1%	19.4%	16.4%
Friday	10.8%	17.0%	16.1%
Saturday	4.4%	6.4%	8.7%

Columns 2 and 3 from Table 5 are shown graphically in Figure 19. Both traffic and PM10 >50 levels are below 2% of the total number of exceedances on Sundays, indicating that weather alone rarely initiates high pollution events. Traffic is heaviest on Monday but the likelihood of PM10 >50 is not as high, presumably due to less sediment build-up on roads. Aerosol production peaks on Wednesday and gradually declines to fairly low rates by Saturday. Although these figures involve only two roads, they clearly show that road traffic is a major driver of aerosol production. However, the delay between traffic build-up during the week and PM10 levels also shows that traffic from sites is tracking sediments onto roads, which peaks mid-week then declines.

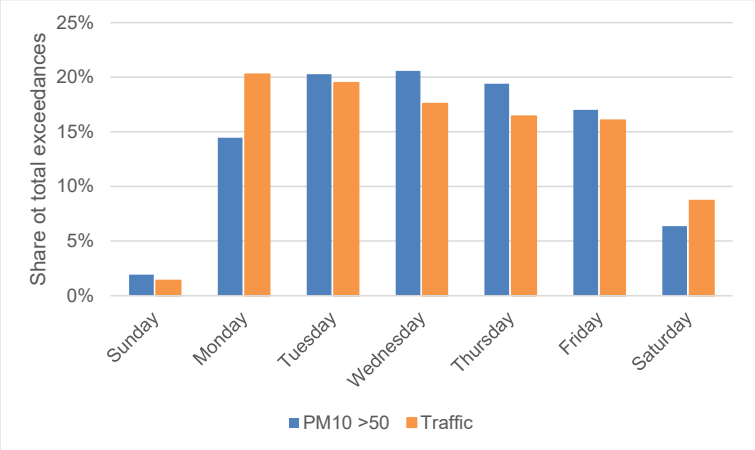


Figure 19. Incidence of PM10 >50 from Brooklyn and traffic volume on a particular day as a proportion of the weekly total (Columns 2 and 3, Table 5).

Adding traffic counts across the whole of Brooklyn conducted by Net Balance as part of their modelling of dust production (Sichlau and Folker, 2012a) and hourly PM10 >50 at both Brooklyn and Footscray, Brooklyn PM10 is clearly affected by traffic on Jones and Bunting Roads whereas Footscray exceedances follow general traffic patterns (Figure 20). Internal traffic starts, peaks and declines up to two hours before general through-traffic peaks and declines. This shows the role of the poorly sealed Jones Road and unsealed Bunting Road in acute levels of dust production affecting the Brooklyn area. Industry-related traffic is therefore the main cause of high levels of PM10 in the Brooklyn area to the south. Jones and Bunting Roads will also reflect traffic activity on unsealed lots adjacent to those two roads better than general traffic figures on all roads, which will have a much higher proportion of through traffic.

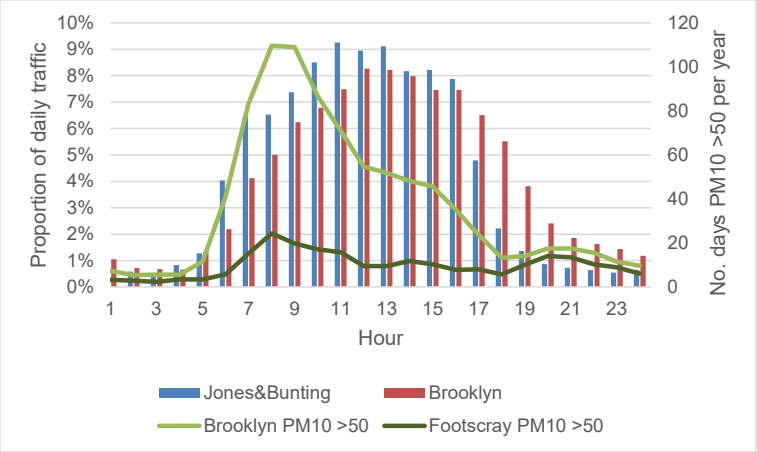


Figure 20. Proportion of daily traffic for Jones and Bunting Roads and across Brooklyn compared with number of days PM10 >50 for each hour of the day for Brooklyn and Footscray.

3.1.4 Soil moisture and PM10

Given the role of moisture in dust suppression, the relationship between rainfall and PM10 levels was tested to determine the role of natural moisture supply in mediating pollution levels. Effective rain was considered as >1 mm rainfall the previous day (higher limits were tested, but made little difference). Comparing the length of days of no effective rainfall (dry spell) and hourly PM10 >50 frequency, showed that PM10>50 was suppressed the following day after effective rainfall by up to half and by a smaller proportion on the third day. By the fourth day, exceedances were at average levels.

For example, if winds are from the northern quarter, at 9 am PM10 >50 is 63% on average. However, one day after effective rainfall the proportion is 38% and after two days, the proportion is 56%. At 1 pm, PM10 >50 occurs on 41% of all days with northerly winds, but one day after rain is 20% and two days after rain is 26%.

This analysis supports EPA assessments that traffic is the major driver of aerosols and dust from the precinct. Weather conditions playing a shaping role but barely initiate events (except perhaps locally with visible dust, not measured by the EPA). Traffic produces aerosols on most dry days from Monday–Saturday. When wind is from the northern quarter these have a significant probability of resulting in elevated levels of PM10, usually in the morning. As winds pick up during the day, these concentrations are diluted as they are blown away from the Brooklyn area, often prompted by a wind change as the sea breeze comes in but also due to increasing atmospheric instability during the day. Days of persistent air pollution are characterized by sustained northerly winds, heavy traffic and drier conditions. Air quality with other wind directions is generally good, with the occasional high levels due to regional fires. For Footscray, elevated levels occur with westerly winds, though not to the same extent as for Brooklyn. For locations like Yarraville, moderate to high levels with occur with north-westerly winds.

The EPA has concentrated their assessments on potential compliance with safety limits, with the main aim of achieving the legislated target of less than 5 days PM >50 per year. Although the daily limit is being exceeded 28 times per year at the Brooklyn monitoring station, our analysis shows there are briefer periods of elevated PM10, most commonly in the mornings, with north winds. These peaks will affect vulnerable members of the population who may be exposed.

Our analysis shows that until these emissions can be reduced simple rule of thumb risks can be calculated in order to communicate risk to vulnerable populations: particularly the young, old and those with underlying respiratory and related health conditions.

3.2 PM2.5

EPA Victoria provided one year's data of PM2.5 levels for Brooklyn and Footscray sampled every three days during 2010–11. During that time, the daily advisory limit of 25 µg/m^3 was not exceeded. The average for Brooklyn over that period was 7.1 µg/m^3 and for Footscray was 6.1 µg/m^3. EPA also provided a conversion factor between light scattering measurements and PM2.5 that allowed us to estimate hourly PM2.5 from October 2010 to August 2013. This is a simple regression that follows Chow et al. (2002).

The daily limit of 25 µg/m^3 was exceeded 107 times per year on an hourly basis at Brooklyn and 50 times per year at Footscray, showing that higher levels are sometimes reached on a short-term basis. We used the annual advisory limit of 8 µg/m^3 as a threshold to determine where and when higher levels were occurring and carried out the same analyses as for PM10 to attribute specific emissions to the Brooklyn Precinct.

The pattern of higher levels of PM2.5 >8 with wind direction and during the day is more complex than for PM10 (Figure 21). Where there was a single peak with northerly winds and during the morning, PM2.5 shows peaks from both the north and south and both daily and nightly peaks (latter not shown). The northerly daytime peak is much larger for Brooklyn than it is for Footscray, showing that its origin is within the Precinct. However, the night-time peak is due to wood smoke and is seasonal, being higher in winter than summer. The southerly peak is approximately one-third the size of the northerly peak and is potentially sourced from the refineries and manufacturing combustion sources to the south.

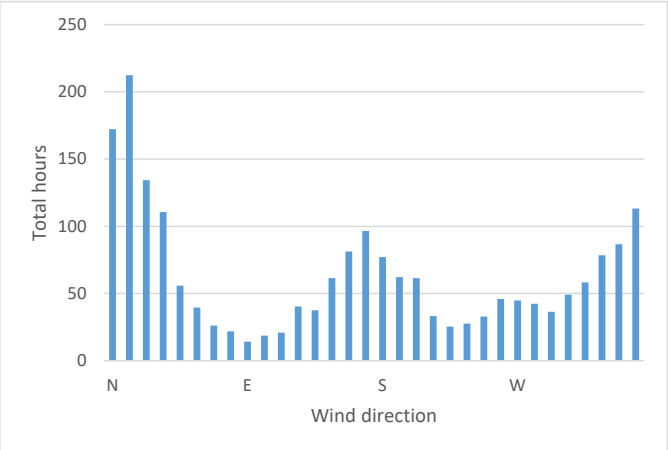


Figure 21. Annual hours of exceedance of PM2.5 greater than 8 micrograms per cubic metre (µgm^{-3}) of air at the Brooklyn monitoring station 2010–2013.

Footscray shows both northerly and southerly influences of PM2.5 with little influence from the west, leading us to conclude that the influence of PM2.5 from the Brooklyn Precinct is a localized effect.

3.3 Dust and odours

Anecdotal information and EPA complaints suggests that visible dust from the site is an issue but there is no formal monitoring beyond complaints data taken by the EPA. There are about a dozen dust complaints in and around the Brooklyn area each year, but the source often cannot be identified. Visibility data is measured as backscattering effects from very small particles and converted into a measure of the attenuation of light over long distances but does not directly measure the presence of visible dust particles.

Figure 22 shows a six-year (2008–2013) spatial distribution of complaints about odour (blue) and dust (red). Individual complaints from each were tallied for each sub-area (see Table 3) to determine rough spatial distribution of odour. Significant proportions are reported from Area 1 (Brooklyn) and Area 3 (Kingsville). Odour complaints have been reducing in both areas but remain high in Brooklyn (Figure 23). There are too few dust complaints to detect a pattern of change (Figure 24).

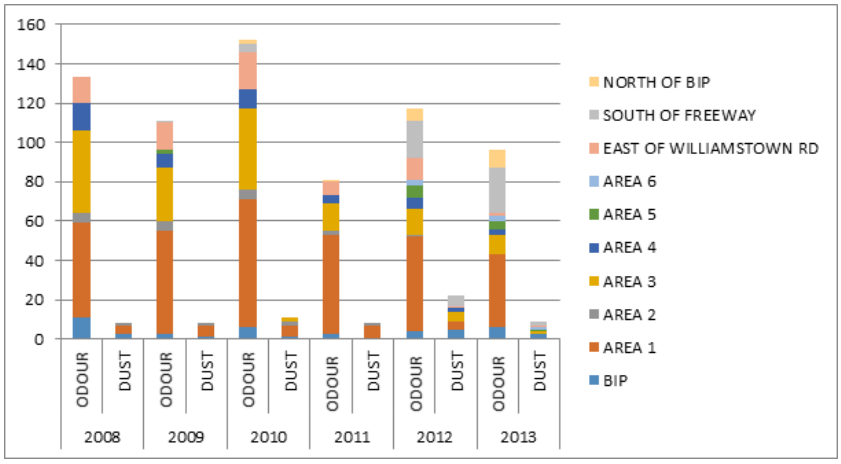


Figure 22. Total odour and dust complaints by year received from EPA for area surrounding Brooklyn Industrial Precinct. Colour segment show the contribution of each area to the yearly total.

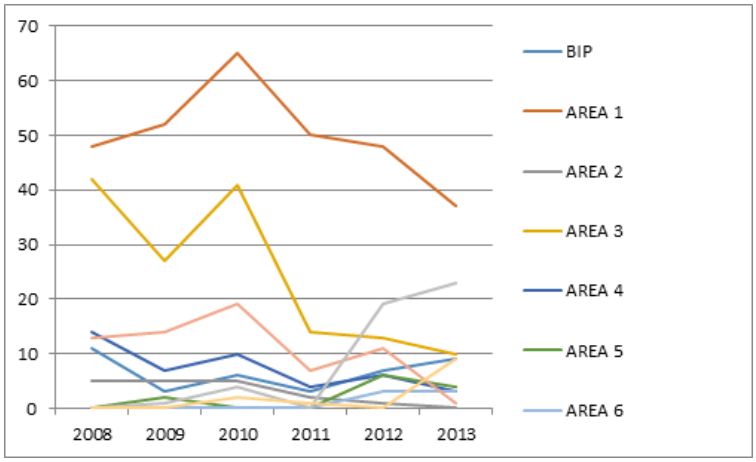


Figure 23. Number of odour complaints by area and year received from EPA for area surrounding Brooklyn Industrial Precinct.

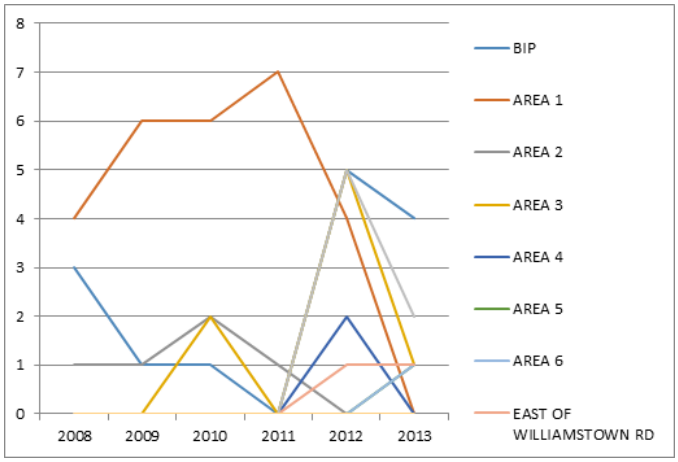


Figure 24. Number of dust complaints by area and year received from EPA for area surrounding Brooklyn Industrial Precinct.

4 Social and environmental costing

Social costing is critical to establishing the business case necessary for the implementation of local water solutions to ameliorate problems of dust and odour at the Brooklyn Industrial Precinct. Social costing is part of a wider economic assessment for the Brooklyn Industrial Precinct that ideally would include:

- Improving business profitability.
- Achieving compliance cost effectively.
- Improving social and environmental returns (liveability).

The first two are crucial for business sustainability (and are key aspects of Brooklyn Evolution), and the third has been identified as part of the Brooklyn Community Reference Group Terms of Reference (Brooklyn Community Reference Group, 2007).

4.1 Rationale and aims of social and environmental impact accounting

Determining the hidden costs of the acute and longer-term effects of dust to residents is crucial to successfully making the case for implementing innovative water solutions in the Brooklyn Industrial Precinct. This recognises community health as a key part of liveability within zones that contain both industrial and residential areas. Savings to water use and water bills will be a motivator for change, but so will social and environmental externalities (both in terms of hidden economic costs, and as important liveability factors in their own right).

Any decisions by business to adopt these solutions will be based on identifying the dollar value of externalities such as:

- improvements in occupational health and safety,
- improvement to environmental sustainability,
- benefits to residents and community, in particular to residential health and liveability, and
- image transformation for sustainable business and good corporate citizenship.

From the governance perspective, assessing both costs and the long-term social returns allows decision-makers to gauge the size of the benefits emerging from each design option, and the flow-on effects of these for the community.

Social research is needed to inform the design work of whole-of-water-cycle planning options and how it can best meet business needs and environmental targets. Filling such knowledge gaps will be crucial to appropriate design, and thus effective implementation, of innovate water solutions. What are the needs that can be addressed by water cycle management, and what opportunities exist to improve this?

Likewise, improvements to the broader environment are key goals of important strategies such as the Kororoit Regional Strategy 2005–2030 (DSE, 2006).

4.1 How social impacts are assessed in this report

The health impacts of air pollution have been assessed by determining the load of the PM10 and PM2.5 dust particles originating within the Brooklyn Industrial Precinct. This done is by assessing the health effects of winds from off the site as the background effect, then assessing the health effects of winds from the site and taking the difference between the two. The resident populations affected are described in Section 2.3.2.

We were unable to determine the exposure to workers onsite because of a lack of information as to numbers, demographics, duration of employment and underlying health data of the working population.

The effects of dust and odours on health and wellbeing are widely acknowledged, but to date we have been unable to quantify these effects due to a lack of detailed survey data and robust estimates of cost in the literature.

Compliance costs have been partially estimated from data obtained from government agencies including Brooklyn City Council. Water costs have been estimated by Browne and Brookes (2014). Limited environmental costings can also be made based on available data.

4.2 Data sources, limitations and assumptions

Higher than average health problems with asthma, cardiovascular issues, and psychological distress are reported in the areas surrounding the Brooklyn Industrial Precinct (Table 6). These higher rates may be due to issues such as socio-economic status, lifestyle issues or air pollution. A drawback is that such data is only available on a local government scale, so is not fine enough to distinguish impacts from the areas directly adjacent to the precinct.

Table 6. Rates of asthma, psychological distress, and indexed figures for heart issues (Victoria average = 1) for LGAs surrounding Brooklyn estate. Figures supplied by the Department of Health (2012 LGA profiles report) and published on http://docs.health.vic.gov.au

Health issue	Brimbank	Hobsons Bay	Maribyrnong	Victoria average
Current asthma (% reporting in previous 12 month period)	11.9	11.5	6.4	10.7
High-very high psychological distress	16.7	10.9	13.9	11.4
Heart issues: NSTEMI O/E	1.3	1.2	1.0	1
Heart issues: STEMI O/E	1.1	1.0	0.8	1
Heart issues: unstable angina O/E	1.2	1.1	0.8	1
Heart issues: heart failure O/E	1.5	1.2	1.0	1
Heart issues: average	1.3	1.1	0.9	1

Potential mortality due to air pollution is estimated with the World Health Organisation's (WHO) AirQ 2.2 program. Sites 1–5 in Figure 8 and site 7 in Figure 10 represent exposure at Brooklyn and Site 6 in Figure 9 represents exposure at Footscray. Lower, middle and upper limits of health effects surveyed as part of the AirQ 2.2 program are included in mortality estimates.

5 Cost to the community

5.1 Exceedance of safe levels of PM2.5 and PM10

The four points below are extracted from the Senate Inquiry into the *Impacts on health of air quality in Australia, 2010-2013* (Community Affairs References Committee, 2013), and synthesises submissions from academics, health professionals, regulators and policy makers in the contemporary Australian context.

> Section 2.13 There is a substantial body of evidence indicating that particulate matter has negative impacts on human health – regardless of the size of particulates. A study published in the Lancet in 2012 found 'ambient particulate matter pollution' to be the ninth leading cause of global disease burden. The National Health and Medical Research Council-funded Centre for Air Quality and Health Research and Evaluation (CAR), reported to the committee that people exposed to the short-term bursts or long-term higher levels of particulate pollution suffer a range of adverse effects, including:
>
> - Increased risk of deaths, particularly due to heart and lung diseases;
> - Increased risk of hospitalisation for heart and lung diseases; and
> - Increased risk of asthma attacks.
>
> Section 2.14 It was reported to the committee that the 'main properties of PM that determine its environmental and health risks are: concentration; size distribution; structure; and chemical composition.' The effects on health vary substantially between geographic settings, partly as a result of variation in the chemical composition of the particulates, which is dependent on their local sources.
>
> Section 2.15 The committee learnt that the size of the PM was the principal determinant of how deeply it is inhaled into the human respiratory system, with smaller particles able to penetrate further into the lungs. As most particles with a diameter >10µm are generally filtered by the nose and throat, PM10 is typically used as the threshold value for studies on the effects of PM on human health.
>
> Section 2.17 PM2.5 is believed to be the most health-hazardous air pollutant, responsible for 10 to 20 times as many premature deaths as the next worst pollutant, ozone. Just as 'every cigarette is doing you damage', every gram of wood smoke or other particle emissions is also causing health problems. Wood smoke is more hazardous than cigarette smoke – in tumour initiation tests it was found to cause 12 to 30 times as many cancers as the same amount of cigarette smoke. The estimated health cost of a kg of PM2.5 emissions in Sydney is more than $235.

The World Health Report (World Health Organization, 2002) has estimated that globally, outdoor air pollution accounts for approximately 1.4% of total mortality, 0.5% of all disability-adjusted life years (DALYs) and 2% of all cardiopulmonary disease. Understanding the health impacts of PM2.5 and PM10 particles, as well as odour, is critical to understanding the direct and indirect costs to society and health. For example, case-crossover analysis of over 5,000 asthma admissions in children within the selected study area in metropolitan Phoenix found a significant correlation between PM_{10} levels and asthma prevalence for children between the ages of 5 and 18 (Office of Children's Environmental Health, 2008; Dimitrova et al., 2012). The study reported an increase from the 25th to 75th percentile of PM_{10} (an increase of 36.4 µg/m^3 resulted in a 13.7% probability of asthma event in that population to the 75th percentile in the study area. Table 7 shows the proportion of mortality due to air pollution for selected health problems.

Table 7. Selected fractions for mortality due to outdoor air pollution for heart and respiratory problems (Ostro, 2004).

Disease	Male (%)	Female (%)	Both sexes (%)
Cardiopulmonary diseases[b]	2	2	2
Respiratory infections	1	1	1
Trachea/bronchus/lung cancers	5	6	5

[a] Source: WHO (2002).
[b] Selected cardiovascular and pulmonary diseases.

5.1.1 Health impacts of particulate exposure in residential areas

Attributable proportions (AP) of illness due to aerosols from the Brooklyn Industrial Precinct were modelled in the World Health Organisation's AirQ 2.2 program for estimating impacts of dust particles. The following input parameters were used in the AirQ 2.2 model:

- Population counts
- Baseline incidences of health problem
- Mea5.8
- n annual particulate measures for whole year, summer and winter
- Distribution of particle measurements by daily average
- Risk ratings (RR) for linking underlying conditions with effects (from Ostro, 2004)

Readings for particle exposure from the Brooklyn station were used for Areas 1–5 and 7, and readings from the Footscray station readings used for Area 6 (Table 8).

Table 8. Parameters for particle exposure used in the AirQ 2.2 long-term exposure model

		Population	Average Daily Exposure (µg/m3)		
			Yearly	Summer	Winter
$PM_{2.5}$	Brooklyn	14,568	7.1	7.3	8.5
	Footscray	3,116	6.1	6.5	6.1
PM_{10}	Brooklyn	14,568	23.0	23.4	21.1
	Footscray	3,116	17.5	19.3	14.0

Assuming these parameters, output readings from AirQ 2.2 for estimated total mortality resulting from long-term exposure to PM2.5 and PM10 are shown in Table 9. Estimated hospital admissions are shown in Table 10. These are the figures attributable to total pollution loads in these areas, not specifically those coming from the Brooklyn Precinct.

Table 9. AirQ estimates for yearly cases of mortality caused by long-term exposure to PM2.5 and PM10 particles.

		Lower Limit			Average Case			Upper Limit		
		Relative Risk	Est. AP %	Est. Cases Mortality	Relative Risk	Est. AP %	Est. Cases Mortality	Relative Risk	Est. AP %	Est. Cases Mortality
$PM_{2.5}$	Brooklyn	1.012	7.0753	**6.4**	1.0240	13.2155	**11.9**	1.0370	19.0125	**17.2**
	Footscray	1.012	5.8841	**1.1**	1.0240	11.1143	**2.1**	1.0370	16.1615	**3.1**
PM_{10}	Brooklyn	1.004	0.5806	**0.5**	1.0060	0.8684	**0.8**	1.0080	1.1545	**1.0**
	Footscray	1.004	0.3805	**0.1**	1.0060	0.5697	**0.2**	1.0080	0.7582	**0.2**

Table 10. AirQ estimates for yearly cases of asthma hospitalisation caused by long-term exposure to PM2.5 and PM10.

		Lower Limit			Average Case			Upper Limit		
		Relative Risk	Est. AP %	Est. Cases Hospital	Relative Risk	Est. AP %	Est. Cases Hospital	Relative Risk	Est. AP %	Est. Cases Hospital
$PM_{2.5}$	Brooklyn	1.0100	5.9664	**1.9**	1.0400	20.2425	**6.5**	1.0800	33.6694	**11.0**
	Footscray	1.0100	4.9520	**0.3**	1.0400	17.2459	**1.2**	1.0800	29.4184	**2.0**
PM_{10}	Brooklyn	1.0048	0.6959	**0.3**	1.0080	1.1514	**0.3**	1.0112	1.6089	**0.4**
	Footscray	1.0048	0.4563	**0.0**	1.0080	0.7582	**0.0**	1.0112	1.0583	**0.0**

Table 9 and Table 10 show the impacts based on the small population zones demarcated by areas 1–5, 6 and 7 totalling a population of 17,684 people. The assumption made in this calculation is that populations beyond these zones are not affected. Displayed below are those figures scaled up to a larger population, which would apply if the airshed of dust particles were broader than the demarcated populations.

Table 11. Summary of hypothetical health impacts scaled up for larger population zone, based on the long-term exposure (average case) in Areas 1-7.

	Population Affected	Annual Asthma Hospital Admission		Annual Excess Mortality	
		Incidence (per 100,000)	Count	Incidence (per 100,000)	Count
Areas 1–7	17,684	45.0	**8.0**	84.5	**15.0**
Size of scaled up affected population	25,000	45.0	**11.3**	84.5	**21.1**
	50,000	45.0	**22.5**	84.5	**42.3**
	100,000	45.0	**45.0**	84.5	**84.5**

5.1.2 Health impacts attributed to the Brooklyn Industrial Precinct

In order to partition off the specific health effects resultant from particulate matter coming directly from the site, exposure effects were calculated for the proportion of time residential areas were downwind of the site, and based on the difference between particle levels when upwind and downwind of the site. This is illustrated in Tables 12 and 13 below.

Table 12. Summary of mortality cases assuming winds blowing to site and away from site at all times. This table was used for calculation and scaling of the estimated modelled excess mortality caused by Brooklyn Industrial Precinct, modelled in Table 13 below.

Site	Particle	Wind Direction	Yearly		Summer		Winter		Unscaled Exposure Effect	
			Incidence (µg/m³)	% time	Incidence (µg/m³)	% time	Incidence (µg/m3)	% time	AP% (95% CI)	Cases (95% CI)
Brooklyn	PM10	From site	35.5	38	41.3	26	32.1	51	1.77 (1.19–2.34)	1.5 (1.0–2.0)
	PM10	Off site	19.6	62	20.1	74	18.9	49	0.57 (0.40–0.80)	0.5 (0.4–0.7)
	PM2.5	From site	7.2	38	7.3	26	7.1	51	13.50 (7.24–18.97)	12.0 (5.4–16.7)
	PM2.5	Off site	6.2	62	6.2	74	6.3	49	11.66 (6.19–16.53)	10.0 (4.4–14.6)
Footscray	PM10	From site	23.2	21	26	18	21.1	24	0.89 (0.59–1.19)	0.2 (0.1–0.2)
	PM10	Off site	18.2	79	18.6	82	17.6	76	0.30 (0.20–0.40)	0.1 (0.0–0.1)
	PM2.5	From site	5.4	21	5.4	18	5.1	24	0.75 (5.12–13.93)	1.9 (1.0–2.7)
	PM2.5	Off site	5.5	79	5.4	82	5.4	76	0.75 (5.12–13.93)	1.9 (1.0–2.7)

Table 13. Estimated cases of excess mortality caused by Brooklyn Industrial Precinct per year, modelled based on the difference in particle exposure when wind blowing from site vs particle exposure when wind not blowing from site.

Site	Particle	Scaled Exposure Effect (Site AP% x time – Nonsite AP% x time) x baseline incidence x population		
		Lower 95% CI	Average	Upper 95% CI
Brooklyn (Areas 1–5, 7)	PM10	0.37	0.55	0.72
	PM2.5	0.49	0.86	1.14
Footscray (Area 6)	PM10	0.02	0.02	0.03
	PM2.5	0.00	0.00	0.00
TOTAL (per annum)		0.88	1.43	1.89

A similar method was used to estimate the excess asthma hospitalisations attributable to Brooklyn Industrial Precinct (Table 14 and Table 15).

Table 14. Summary of asthma hospitalisation cases assuming winds blowing to site and away from site at all times. This table was used for calculation and scaling of the estimated modelled excess hospitalisation caused by Brooklyn Industrial Precinct, modelled in Table 15 below.

Site	Particle	Wind Direction	Yearly		Summer		Winter		Unscaled Exposure Effect	
			Incidence (µg/m³)	% time	Incidence (µg/m³)	% time	Incidence (µg/m3)	% time	AP% (95% CI)	Cases (95% CI)
Brooklyn	PM10	From site	35.5	38	41.3	26	32.1	51	2.34 (1.41–3.25)	0.6 (0.3–0.8)
	PM10	Off site	19.6	62	20.1	74	18.9	49	0.79 (0.48–1.11)	0.1 (0.0–0.1)
	PM2.5	From site	7.2	38	7.3	26	7.1	51	20.63 (6.10–34.21)	5.1 (1.5-8.4)
	PM2.5	Off site	6.2	62	6.2	74	6.3	49	18.03 (5.21-30.56)	4.4 (1.3-7.5)
Footscray	PM10	From site	23.2	21	26	18	21.1	24	1.19 (0.71–1.65)	0.2 (0.1–0.2)
	PM10	Off site	18.2	79	18.6	82	17.6	76	0.40 (0.24–0.56)	0.0 (0.0–0.0)
	PM2.5	From site	5.4	21	5.4	18	5.1	24	15.25 (4.31-26.47)	0.8 (0.2–1.4)
	PM2.5	Off site	5.5	79	5.4	82	5.4	76	15.25 (4.31-26.47)	0.8 (0.2–1.4)

Table 15. Estimated cases of excess asthma hospitalisations caused by Brooklyn Industrial Precinct per year, modelled based on the difference in particle exposure when wind blowing from site vs particle exposure when wind not blowing from site.

Site	Particle	Scaled Exposure Effect (Site AP% x time – Nonsite AP% x time) x baseline incidence x population		
		Lower 95% CI	Average	Upper 95% CI
Brooklyn (Areas 1–5, 7)	PM10	0.11	0.19	0.27
	PM2.5	0.08	0.26	0.34
Footscray (Area 6)	PM10	0.02	0.04	0.04
	PM2.5	0.00	0.00	0.00
TOTAL (per annum)		0.21	0.49	0.65

We also estimated changes in asthma rates from the Arizona PM10 study (Office of Children's Environmental Health, 2008) based on PM10 levels and prevailing winds from the Brooklyn site. This provided an estimate of an added 2.3% and 0.4% of asthma cases for Brooklyn and Footscray, respectively.

The proportion of added hospitalization from both PM10 and PM2.5 attributed to the Brooklyn Precinct (Table 14) of the total asthma burden of air pollution shown in Table 10 is 6.6% for Brooklyn and 3.3% for Footscray. Applying these as minimum rates to the existing population of asthma sufferers in the areas, affected, we estimate that about 85 extra people are directly affected by the Brooklyn Precinct. As this assumes hospitalization flows pro rata through to total asthma cases, this can be considered a minimum estimate.

Table 16. Local population affected by asthma in areas 1–7 and minimum additional population affected by air pollution from the Brooklyn Industrial Precinct assuming hospitalization rates flow through to total cases.

Area	Boundaries	Population	Asthma rates	Local population asthma sufferers	Additional population affected
1	Brooklyn	1,637	0.119	195	12.9
2	Kingsville	1,574	0.064	101	6.6
3	Kingsville	1,470	0.064	94	6.2
4	Kingsville	3,112	0.064	199	13.1
5	Kingsville	3,525	0.064	226	14.9
6	West Footscray	3,116	0.064	199	6.6
7	North Altona	3,250	0.115	374	24.7
	Brooklyn (1–5, 7)			1188	78
	Footscray (6)			199	7

5.2 Direct health costs of dust

Barnes et al. (1996) and Akobundu et al. (2006) outline the three components of costing health outcomes that are accepted practice:

1. *Direct costs* cover medical resources consumed, like consultations (specialists, general and hospital practitioners), drugs, in-patient and out-patient hospitalizations, emergency room stays and cost of rehabilitation.
2. *Direct non-medical costs* cover non-medical resources consumed in direct connection with the health outcome: i.e., cost of social support (such as home help), transportation and major home modifications.
3. *Indirect costs* cover different types of resources lost:
   a. Loss of productive work by patient (either due to time off work or a poorer access to employment due to poorer health).
   b. Loss of productive work by patient's family and friends (e.g., mother taking time off work).
   c. Loss of productive work due to patient's early retirement or premature death.
   d. Intangible costs such as unhappiness and stress.

5.2.1 Direct and indirect valuation of mortality

The standard way to cost mortality is through the value of a statistical life (VSL). It takes into account direct contributions to the economy such as lifetime earnings, but also includes indirect values such as how people trade-off risks against income. This is a complicated and contested issue. For example, in some situations where risk is traded off against income, as in the acceptance of a dangerous occupation, the trade-off may not be through choice but necessity. Non-monetary measures are

Quality Adjusted Life Years (QALY) and Disability Adjusted Life Years (DALY), to be sought and avoided by policy measures, respectively.

A 2008 review of VSL for the Office of the Australian Safety and Compensation Council produced an estimate of $6 million in 2006 values for use in Australian applications (Access Economics, 2008). This converts to $7.2 million in 2011 values. Therefore the added mortality costs (both direct and indirect, including lost lifetime productivity) from Table 13 are estimated to be:

Total mortality-associated costs = Total cases x value
= 0.88, 1.43, 1.89 x $7.2 million
= $10.3 million with a range of $6.3 to $13.6 million

5.2.2 Direct valuation of asthma admissions

To calculate the direct cost of asthma stemming from airborne particle exposure, we estimated hospitalisation from two sources: the AirQ model and the Arizona air quality study (Office of Children's Environmental Health, 2008).

Using the AirQ model, hospital admissions were calculated from Table 6, while direct costs of GP visits and pharmaceuticals were estimated based on hospital admissions. A comprehensive report on the economic cost of asthma (Australian Institute of Health and Welfare, 2013) estimates the annual cost of asthma within the health sector to be $655 million, of which $128 million results from a total of 37,830 cases of hospitalisation of average stay 2.1 days. The economic cost per admission is therefore $3,383.56. Within Areas 1–6, the economic cost related to asthma hospitalisation due to exposure to PM_{10} and $PM_{2.5}$ equates to:

Total asthma hospitalisation cost = cases x average cost per admission
= 0.21, 0.49, 0.65 x $3,383.56 = $1,658 with a range of $711 to $2199

Scaling up to include total economic costs of asthma, including GP visits and pharmaceuticals based on a multiplier of:

Multiplier = Total costs of asthma hospitalisation / Total costs of asthma
= $128 million / $655 million
= 5.12

Direct asthma costs = $8,489 per annum with a range of $3,638 to $11,260

5.3 Indirect health costs of dusts and odour

Although we only have complaint data for odour, the high level of complains, particularly in the Brooklyn residential area (Area 1) and Kingsville (Area 3) will affect health and wellbeing as supported by the scientific literature. The relationship between exposure to industrial odours and annoyance levels is stronger for frequency and unpleasantness (Miedema et al., 2000; Sucker et al., 2008). Aatamila et al. (2011) found a clear link between annoyance and physical symptoms for odours produced by green waste processing. Schiffman et al. (1995) compared populations exposed to large-scale meat processing with control populations matched for gender, ethnicity, age and education. They found significantly higher levels of tension, depression, anger, fatigue and mood disturbance amongst the exposed population. Long-term exposure to unpleasant odours is therefore associated with a decrease in wellbeing and quality of life (confirming common sense).

The indirect costs of air pollution, based on PM10 levels are assessed from studies that use two methods:

1. The relationship between willingness to pay for clear air as a function of average household income after other factors have been removed, and
2. The relationship between happiness and income as a function of air pollution levels.

Bayer et al. (2009) estimate marginal willingness to pay given a wide range of variables on household income and air quality measured as PM10 levels. Lower income is associated with higher pollution areas after a range of confounding factors have been allowed for. They factor in the price of moving from one location to another as not being a "free" service of exercising the choice of moving to a clean air location. The result is expressed as a cost of household income for a 1 $\mu g/m^3$ reduction in PM10 (US$149 to US$185 in 1982–1984 prices). This has been converted into factor of median household income to make it price invariant and is applied to the Brooklyn–Footscray area.

Levinson (2012) uses self-reported happiness and income data as a function of air pollution to derive a hedonic (shadow) price for pollution. This was converted into a factor of median household income per 1 $\mu g/m^3$ reduction in PM10. By explicitly linking happiness to income and unhappiness to short-term pollution events, this study derives a hedonic value for wellbeing based on pollution levels. Again, this has been applied to the study area. Two factors have been chosen: the first represents pollution and income only, and the second allows for demographic and local effects (such as age, weather, employment, relationships). Although the latter will be different in the study area, the willingness to pay relationship thus established was almost double that due to pollution and income alone.

Increasing the amenity of an area will also increase house and land prices. This is often seen as a benefit for home owners, but a negative for renters, although both get the same health and welfare benefits. There is little data available quantifying this effect, but in a US study, Grainger (2012) estimated that just less than one half of the increase in property prices was transferred through to renters after a reduction in pollution. Collectively, these studies show that home owners will get a dual benefit through improved air quality and increased house prices and that renters will receive a net benefit though improved health but that this will be partially offset by rising rents. We do not include any estimates based on increased house prices here, but rely on methods that use household income.

The Levinson (2012) study is the most applicable to this situation, because it links well-being, income and pollution events. Although the benefits are measured in units of PM10, they will extend to all

simultaneous pollution events, especially those that are visible and olfactory – that people can see and smell (in order to register their discomfort).

The social benefits of removing dust-related pollution from the site was calculated by multiplying scaling factors from the above studies by average household income on the exposed areas identified in Brooklyn and Footscray. Table 17 shows average annual income for postcodes covering Areas 1–7. These annual incomes and households in Table 3 were multiplied with factors from the Bayer et al. (2009) and Levinson (2012) studies to estimate the social benefits of removing dust pollution from the precinct.

Table 17. Average household weekly and annual income from postcodes covering areas identified as being exposed to dust pollution as listed in Table 3.

Postcode area	Average household weekly income	Average household annual income	Households renting
Brooklyn (corresponds to Area 1)	$1,029	$53,508	36.9%
Kingsville (corresponds to Areas 2–5)	$1,372	$71,344	38.2%
West Footscray (corresponds to Area 6)	$1,129	$58,708	38.0%
Altona North (corresponds to Area 7)	$910	$47,320	27.3%
VIC average			26.5%

For the Brooklyn section, average annual PM10 from the industrial precinct is 25.4 µg/m^3, while non-Brooklyn PM10 is 19.6 µg/m^3, suggesting a potential benefit of up to 5.8 µg/m^3. For Footscray, these numbers are 19.2 and 18.2 µg/m^3 respectively, potentially producing a 1 µg/m^3 improvement. Potential improvements in social welfare therefore are equivalent to an annual benefit of $4.1 to $8.9 million per µg/m^3 with a median value of $4.8 million. If the total pollution burden were to be removed from the site, then the social benefit to residents would be an estimated $23.5 to $51.7 million every year with a median value of $27.8 million (Table 18), discounting over time as people move on or away from the region. Per head of population, this is equivalent to $0.87 per day per 1 µg/m^3 improvement and $5.03 per day for full improvement in air quality.

Table 18. Estimated social benefits (measured as general improvements in wellbeing) in 2011 dollars of removing dust pollution from the Brooklyn Industrial Precinct, based on two studies (Bayer et al., 2009; Levinson, 2012) scaled to local household income and population.

	Bayer et al. low	Bayer et al. high	Levinson low	Levinson high	Median value
Factor					
Brooklyn ($million per 1 µg/m3)	$3.9	$4.9	$4.4	$8.6	
Footscray ($million per 1 µg/m3)	$0.8	$1.0	$0.9	$1.8	
Total per 1 µg/m3 ($million)	$4.1	$5.0	$4.6	$8.9	$4.8
Total potential ($million)	$23.5	$29.1	$26.6	$51.7	$27.8

5.4 Compliance costs

Compliance costs have been estimated from data gathered by Brimbank City Council and Browne and Brookes (2014). These include the cost of maintaining an officer in the EPA, Council and the EPA providing notices and hearing attendance. Direct costs of suppression through water application and road sweeping are also included. Industry contributions are tallied from the price of water used in dust suppression and are almost certainly an underestimate (Table 19). Compliance costs are partially offsetting a certain amount of air pollution, but it is difficult to determine by how much.

Compliance costs that fail to address the problem cause is an issue for agencies, business and the community, because costs will remain an ongoing issue until the cause is addressed. Short-term solutions like using water for dust suppression may temporarily reduce pollution levels, but the continual redistribution of sediments on the site mean that such costs will be recurring.

One-off solutions, such as the removal of sediments from roadsides, will reduce pollution loads for a longer period, but these measures will also be subject to long-term build up and reactivation if not tackled at the source.

Table 19. Estimated compliance costs for government agencies and industry for managing air pollution from the Brooklyn Industrial Precinct

Organization & Cost	2012–2013 ($000)	2013–2014 ($000)
Ongoing		
Brimbank City Council	$87	$90
VicRoads	$28	$28
EPA	$200	$200
Industry*	$270	$348
TOTAL	**$584**	**$665**
One-off		
Council	$20	$15
VicRoads	$20	$170
TOTAL	**$40**	**$185**

5.5 Environmental costs

Costs such as onsite flooding, sediment build up and clean-up have not been assessed. For water-borne pollution estimated as coming off the site: sediments (150.8 tonnes), phosphorus (192 kg) and nitrogen (1,543 kg) are covered by plans to manage water quality in Melbourne's waterways (MWC & EPA, 2009). The target for the removal of nitrogen from Melbourne's waterways is 500 tonnes of which Kororoit and Stony Creeks can play a small part of some or all of the 1.5 tonnes estimated to come from the site are abated. A further goal of reducing urban flows to pre-settlement conditions would see current site runoff reduced by about 75% if applied pro-rata on the site.

Values for environmental quality at the catchment or regional scale have not been calculated. The cost-effectiveness of management options is the main way of valuing efforts to reduce pollutant loads in the environment. Recent estimates from south-east Queensland have some relevance to the site because they are taken from a range of projects (Hall, 2012). The potential for individual projects to remove all three pollutants provides the potential for considerable cost savings, providing environmental benefits onsite and to the Kororoit Creek catchment.

Table 20. Selected estimates of cost-effectiveness for stormwater management, taken from example in SE Queensland (Hall, 2012). Estimates for nutrients include and central, low and high estimate.

Abatement option	Suspended solids ($ per tonne)	Nitrogen ($ per kg)	Phosphorus ($ per kg)
Stormwater re-use (50 ML/yr)		$260 ($90–$730)	$1,230 ($390–$3,900)
Stormwater re-use (10 ML/yr)		$1,970 ($660–$5,640)	$9,470 ($2,960–$29,600)
Swales	$30	$22	$454
Tanks (5 kL) 50 kL yield/20yrs	$34	$320	$5,130

5.6 Direct and indirect costs

This section collates the various monetary and social costs and some of the potential benefits detailed in the report (Table 21). Note that all values have been updated to 2013 dollars (health and wellbeing costs and benefits have been converted from 2011 dollars).

Collated monetary costs are $859,000 for 2013–14. Most of the cost is for dust suppression and compliance. Health costs are only a small part of this total, but they lack estimates for heart-related illness and hospitalisation due to elevated air pollution. Social costs from mortality are estimated as being equivalent to $10.7 million per year. Wellbeing costs have a central estimate of $29 million per year but range from $23.5 million to $53.9 million. These are not direct costs to the economy but are value-equivalent measures based on relationships between income, happiness and wellbeing. These costs would become benefits if pollution were to be abated through management actions.

We lack data showing how much PM10 and PM2.5 is being avoided by dust suppression and related land-use management, so cannot fully assess the benefits. However, the large estimated social costs at current levels of pollution suggest that suppression and compliance costs are providing substantial social benefits in terms of avoided stress, illness and mortality and increased wellbeing.

Table 21. Collated direct and social costs and benefits of air pollution in $1000 attributed to the Brooklyn Industrial Precinct taken from Section 4.2, Table 18 and Table 19 and updated to 2013 dollars. Indirect costs contain low, median and high estimates.

Impact	Factor	Monetary costs (2013–2014) ($1000)	Social costs ($1000)	Social benefits ($1000)
Pollution experienced	Added mortality		$10,700 ($6,300–$13,600)	$10,700 ($6,300–$13,600)
	Asthma hospitalisation	$8.9 ($3.8–$11.9)		$8.9 ($3.8–$11.9)
	Wellbeing per 1 µg/m^3		$5,000 ($4,200–$9,300)	$5,000 ($4,200 to $9,300)
	Wellbeing total		$29,000 ($23,500–$53,900)	$29,000 ($23,500–$53,900)
Pollution avoided short-term	Dust suppression and compliance	$665		
Pollution avoided long-term	Dust removal and VCAT costs	$185		
Total		$859	$39,700	$39,709

6 Conclusions

This baseline report explores the social and ecological systems influencing the water cycle within the Brooklyn Industrial Precinct, especially aspects influencing the generation and management of dust and aerosols. As such, it seeks to:

- establish the direct and indirect monetary costs of health impacts of dust and odour on the site;
- identify values associated with the water cycle on the site; and
- aims to set a baseline that would serve as the basis for analysing and identifying potential integrated water management strategies for Brooklyn Industrial Precinct's air quality issues.

Three systems of value have been identified:

1. The on-site urban water system.
2. The Kororoit Creek catchment.
3. The airshed linked to the precinct.

6.1 The Brooklyn Industrial Precinct Urban Water System

Key aspects of the precinct urban water system relevant to values on the site are (drawn from (Browne and Brookes, 2014):

- High levels of water use by some customers leading to the potential for substitution with alternative water sources and site design. For a variety of reasons, we are unable to bring the current costs of onsite water use into this baseline assessment.
- The limited water infrastructure onsite leading to poorly controlled drainage and flooding, and sediment problems in many areas. This will also have costs, which are at present unquantified.
- High levels of runoff, sediment and nutrients from the site affect adjacent waterways, degrading environmental values.

6.2 The Kororoit Creek Catchment

Kororoit Creek is an important urban waterway and its relationship with the Precinct is important in the follow ways:

- The precinct reduces the visual amenity of the creek and the physical amenity of the eastern side of the creek valley due to the encroachment of fill into the valley.
- Intercepting sediment and nutrients entering the creek waters is an important part of addressing the Kororoit Creek Regional Strategy 2005–2030.
- Initial data suggests that there are cost-effective options for limiting poorly controlled runoff, sediments and nutrients from the site, improving environmental values within the catchment.

6.3 The Brooklyn Industrial Precinct Airshed

The major focus of this report is dust and aerosol production within the Brooklyn Industrial Precinct which is distributed by the precinct airshed, affecting the health and wellbeing of adjacent residents. Exhaustive analysis of EPA monitoring data, local rainfall data and traffic data has allowed us to paint a precise picture of the water, sediment, transport and dust cycle contributing to the generation of

airborne dust and aerosol particles. This assessment has also allowed us to nominate the proportion of PM10 and PM2.5 particles coming from the site as compared to those of regional origin. Combined with health modelling, we have then been able to asses a range of direct monetary and indirect social costs, which can become benefits if air pollution is reduced.

6.3.1 Dust and aerosol production and levels

- Two EPA monitoring stations, Brooklyn and Footscray, register pollution peaks that can be directly attributed to the precinct. Brooklyn carries about five times the added aerosol burden of Footscray. Brooklyn experiences an average of 28 days per year of PM10 >50, exceeding the legislated limit of 5 days per year. Footscray experiences 3 days on average.
- High rates of air pollution at Brooklyn are associated with winds coming from the northern quadrant and time of day, being highest at 8–9 am. High pollution occurs on weekdays and moderate pollution on Saturday, all linked to transport movement. At Footscray high pollution occurs with westerly winds, with similar timing to Brooklyn.
- For Brooklyn, average PM10 levels are 35.5 µg/m^3 when winds are from the north (38% of the time) and 19.6 µg/m^3 when winds are from other directions (62% of the time). At Footscray, average PM10 levels are 23.2 µg/m^3 when winds are from the west (21% of the time) and 18.2 µg/m^3 when winds are from other directions (79% of the time).
- Wind rarely initiates significant pollution events on its own, as shown by the low number of exceedances on Sunday (1.4% of total hourly exceedances of PM10 >50 µg/m^3).
- Dust and aerosol production is associated with the morning traffic rush, initiated around 6 am. The timing at Brooklyn is closely linked to internal traffic, whereas Footscray is more influenced by through traffic, which rises and peaks slightly later.
- Atmospheric conditions are vital for the persistence of plumes containing PM10. They include wind direction, wind speed and atmospheric stability. Northerly winds and stable conditions are important for the Brooklyn site. During the day atmospheric instability increases, commonly causing the plume to rise and disperse. Strong northerly winds are also highly correlated with pollution events but are less common. This is also the case for westerly winds and Footscray.
- Data for PM2.5 directly sampled was extrapolated to hourly data, allowing us to identify contributions to the Brooklyn and Footscray monitoring stations. For Brooklyn, average PM2.5 levels are 7.2 µg/m^3 when winds are from the north (38% of the time) and 6.2 µg/m^3 when winds are from other directions (62% of the time). For Footscray, there is essentially no difference, with no meaningful contribution of PM2.5 from the Precinct.

6.3.2 The role of sediments and moisture

- Sediment supply and movement is very important for the production of dust and aerosols. The timing of plume initiation in the morning can be linked to traffic, but slightly lower rates on Mondays when week-high traffic occurs, shows that transport is tracking sediments from lots to roads. This sediment builds up during the week.
- Aerosols will be produced by traffic if roads are dry and sediment is present. Watering can suppress dust but only temporarily, as transport will rapidly dry roads out. Rainfall data shows that dust production is back to normal within 2 days of effective rainfall in most cases. Dust suppression by rainfall is therefore short-lived, although lower levels of PM10 during 2011, shows that sustained high rainfall does suppress dust production.
- There are indications that when the site becomes very dry, PM10 production is slightly lower, indicating that very dry sediment is transported less efficiently by vehicle movement.

- Sediment containing some moisture is more likely to adhere to vehicles. Therefore, while wetting down sediment will hamper dust production it promotes sediment redistribution by vehicle transport. In wet conditions, mud will be tracked further from sites onto main roads.
- Sediment transport within lots and onto roads is a perennial problem. Dust suppression using water therefore has limited effectiveness, because it does not address sediment production and transport. The best strategies will be those that combine road and drainage improvements, site modification, sediment stabilisation, wheel washes and transport movement plans, and use dust suppression with water as a last resort.

6.3.3 Health and wellbeing

- Even though the difference between PM10 levels from the precinct is much higher than for PM2.5, the health impacts of PM2.5 are larger.
- If at Brooklyn, winds are blowing from the north quarter (NW to NE) the likelihood of PM10 >50 is 62% at 9 am. At midday, this is probability is 42%, a level sustained to 3 pm. By 6 pm, even if the winds are still from the north, the likelihood of exceeding PM10 >50 falls to 11%.
- Given wind direction and estimates of atmospheric stability, it is possible to develop accurate estimates of likely exposure to PM10 over the course of a day. For example, those with respiratory conditions or heart disease would be advised not to exercise on weekday mornings if winds are from the NW to NE quadrant, but would be fine most afternoons, with exceptions for days of high pollution marked by strong northerly winds.
- Estimated increased mortality due to particulates from the precinct is 1.4 persons per year with a range of 0.9 to 1.9. Estimated increased asthma hospitalisations due to particulates from the precinct is 0.5 with a range of 0.2 to 0.7. Up to 85 extra people may be affected by asthma due to added pollution levels.
- Workers on the site will be affected by even higher levels of particulates than measured at the Brooklyn monitoring station, but we currently have no information as to their number, vulnerability or tenure at the site, by which to judge exposure.

6.3.4 Direct and indirect costs

- Collated monetary costs are $859,000 for 2013–14. Most of the cost is for dust suppression and compliance. Health costs are only a small part of this total, but it lacks estimates for heart-related illness and hospitalisation due to elevated air pollution.
- Social costs from mortality are estimated as being equivalent to $10.7 million per year but range from $6.3 to $13.6 million.
- Equivalent costs for social wellbeing have a central estimate of $29 million per year, but range from $23.5 million to $53.9 million. These are not direct costs to the economy, but are value-equivalent measures based on relationships between income, happiness and wellbeing. These costs would become benefits if pollution were to be abated through management actions.
- Total social cost per annum of air pollution from the precinct is equivalent to $39.7 million with a range of $29.8 million to $67.5 million. While this dwarfs direct health costs and costs of maintenance, suppression and compliance, removing air pollution as part of an integrated water systems strategy would deliver these costs as social benefits, to be accrued over the long term.

References

Aatamila, M., Verkasalo, P.K., Korhonen, M.J., Suominen, A.L., Hirvonen, M.-R., Viluksela, M.K. and Nevalainen, A. (2011) Odour annoyance and physical symptoms among residents living near waste treatment centres. *Environmental Research*, **111**, 164-170.

Access Economics (2008) *The Health of Nations: The Value of a Statistical Life* Office of the Australian Safety and Compensation Council, Canberra, pp. 171.

Akobundu, E., Ju, J., Blatt, L. and Mullins, C.D. (2006) Cost-of-Illness Studies. *Pharmacoeconomics*, **24**, 869-890.

Australian Institute of Health and Welfare (2013) Asthma hospitalisations in Australia 2010-11. *Cat No. ACM 27*, Australian Institute of Health and Welfare, Canberra, pp. 43.

Barnes, P., Jonsson, B. and Klim, J. (1996) The costs of asthma. *European Respiratory Journal*, **9**, 636-642.

Bayer, P., Keohane, N. and Timmins, C. (2009) Migration and hedonic valuation: The case of air quality. *Journal of Environmental Economics and Management*, **58**, 1-14.

Brooklyn Community Reference Group (2007) Brooklyn Community Reference Group (BCRG): Agreed Terms of Reference, Brooklyn Community Reference Group, Brooklyn, pp. 4.

Browne, D. and Brookes, K. (2014) Living Brooklyn Integrated Water Cycle Management Strategy, E2 Design Lab, Melbourne, pp. 30.

Chow, J.C., Watson, J.G., Lowenthal, D.H. and Richards, L.W. (2002) Comparability between PM2. 5 and particle light scattering measurements. *Environmental Monitoring and Assessment*, **79**, 29-45.

Community Affairs References Committee (2013) Impacts on health of air quality in Australia. , Commonwealth of Australia, Canberra, pp. 78.

Dimitrova, R., Lurponglukana, N., Fernando, H., Runger, G., Hyde, P., Hedquist, B., Anderson, J., Bannister, W. and Johnson, W. (2012) Relationship between particulate matter and childhood asthma–basis of a future warning system for central Phoenix. *Atmospheric Chemistry and Physics*, **12**, 2479-2490.

DSE (2006) *Kororoit Creek Regional Strategy 2005–2030* Department of Sustainability and Environment, Melbourne, pp. 148.

EPA (2005) Air monitoring alongside the Westgate Freeway in Brooklyn – March to November 2004. *Information Bulletin*, Environmental Protection Authority, Victoria, Carlton, pp. 10.

EPA (2011) Year 1 of air monitoring at Brooklyn: November 2009 to October 2010. *Information Bulletin*, Environmental Protection Authority, Victoria, Carlton, pp. 7.

EPA (2012) Year 2 of air monitoring at Brooklyn: November 2010 to October 2011. *Information Bulletin*, Environmental Protection Authority, Victoria, Carlton, pp. 3.

EPA (2013a) Year 3 of air monitoring at Brooklyn: November 2011 to October 2012. *Information Bulletin*, Environmental Protection Authority, Victoria, Carlton, pp. 2.

EPA (2013b) Francis Street Monitoring Program Final Report. *Information Bulletin*, Environmental Protection Authority, Victoria, Carlton, pp. 4.

Grainger, C.A. (2012) The distributional effects of pollution regulations: Do renters fully pay for cleaner air? *Journal of Public Economics*, **96**, 840-852.

Hall, M.R. (2012) The Cost of Pollution: Supporting Cost-effective Options, Evaluation and Pollution Reduction. *Urban Water Security Research Alliance Technical Report No. 61*, Urban Water Security Research Alliance Brisbane, Australia, Brisbane, pp. 84.

Levinson, A. (2012) Valuing public goods using happiness data: The case of air quality. *Journal of Public Economics*, **96**, 869-880.

Meinhardt Infrastructure & Environment and McGauran Giannini Soon (2012) *the brooklyn evolution* Brimbank City Council, Keilor, pp. 57.

Miedema, H., Walpot, J., Vos, H. and Steunenberg, C. (2000) Exposure-annoyance relationships for odour from industrial sources. *Atmospheric Environment*, **34**, 2927-2936.

MWC & EPA (2009) *Better Bays and Waterways: A Water Quality Improvement Plan for Port Phillip Bay and Western Port* Environmental Protection Authority Victoria, Carlton, pp. 147.

Office of Children's Environmental Health (2008) Protecting Our Children: Assessing the Link between PM10 Pollution and Childhood Asthma in Maricopa County, Arizona Department of Environmental Quality, Phoenix, Arizona, pp. 11.

Ostro, B. (2004) Outdoor Air Pollution: Assessing the environmental burden of disease at national and local levels. *WHO Environmental Burden of Disease Series No. 5*, World Health Organization, Geneva, pp. 54.

Schiffman, S.S., Sattely Miller, E.A., Suggs, M.S. and Graham, B.G. (1995) The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. *Brain research bulletin*, **37**, 369-375.

Sichlau, B. and Folker, M. (2012a) *Brooklyn Industrial Precinct Road Dust Assessment 2012* Net Balance, Melbourne, pp. 24.

Sichlau, B. and Folker, M. (2012b) *Brooklyn Industrial Precinct Road Dust Abatement Options Assessment 2012* Net Balance, Melbourne, pp. 33.

Sucker, K., Both, R., Bischoff, M., Guski, R., Krämer, U. and Winneke, G. (2008) Odor frequency and odor annoyance Part II: dose–response associations and their modification by hedonic tone. *International Archives of Occupational and Environmental Health*, **81**, 683-694.

World Health Organization (2002) *The World Health Report 2002: Reducing risks, promoting healthy life,* World Health Organization, Geneva, pp. 248.