DOMESTIC WOOD SMOKE REDUCTION IN THE URBAN ENVIRONMENT

Prepared for
The Firewood Association of Australia Inc.
by QA Pty Ltd

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FIREWOOD ASSOCIATION OF AUSTRALIA INC ™

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EXECUTIVE SUMMARY

This project was initiated by the Firewood Association of Australia Inc. (FAA) and was conducted with the assistance of The Hills Shire Council in NSW. The purpose of the project was to develop a cost effective, practical methodology that can be readily used by councils to improve winter air quality and to also minimise the number of complaints councils receive about domestic wood smoke.

In recent years there has been a lot of attention paid to pollution caused by ultra-fine particles suspended in the atmosphere; that is particles less than 2.5 microns in diameter ($PM_{2.5}$). Even though Australia currently enjoys a very high standard of air quality, much of the Northern hemisphere is now badly affected by fine particle pollution. Apart from the visual impact of the haze caused by fine particle pollution, many health authorities are becoming increasingly concerned about the impact on human health from prolonged exposure to ultra-fine particles. These very small particles can penetrate deep into the lungs, while larger particles in the air are generally trapped in the nose or throat. If exposed to air polluted by fine particles for long enough, the normal cleaning function in the lungs can eventually become overloaded causing health problems.

According to the National Pollution Inventory[1] (NPI), smoke from domestic wood fires only constitutes 1.4% of the total fine particle pollution in Australia. However, smoke pollution from domestic wood heating attracts a lot more attention than the major contributors to fine particle pollution, such as wildfires, crop residue burns, diesel exhausts and coal dust, especially when it occurs in densely populated areas. In recent years all levels of government have been motivated to take positive steps to minimise domestic wood smoke pollution, partly as a consequence of the apparent health impacts of prolonged exposure to fine airborne particles, but mostly as a result of pressure from residents to improve the air quality in their local community during the winter months.

Local government employees, usually environmental health officers, are often faced with the task of dealing with complaints made by residents about a neighbour who is causing nuisance wood-smoke. Occasionally, state environment protection agencies receive complaints relating to wood smoke. In some towns and cities in Australia, topography and temperature inversions can combine to trap wood smoke to create unacceptable air quality over an entire air-shed.

Most councils deal with complaints about wood smoke by notifying the offending householder by letter that the council has received a complaint about the smoke coming from their wood fire. Usually the householder is offered advice on ways to reduce their smoke emissions and the letter may contain a warning that the householder may be prosecuted if smoke emissions continue. The problem with this reactive response to wood smoke complaints is that many of them are instigated as a result of disputes between the neighbours over other issues.

[1] NPI 2011, 2010/2011 data within Australia – Particulate Matter 10 μm from All Sources, National Pollutant Inventory, Department of Sustainability, Water, Population and Communities.

When this is rightly or wrongly perceived to be the case by the complained about householder, they will generally dismiss the complaint as unjustified and not change their wood fire operating practice. On the other hand, many people will not complain about a neighbour's excessive smoke, and will suffer unacceptable air quality in order to maintain a friendly or harmonious relationship with their offending neighbour.

By taking a more proactive approach to domestic wood smoke control, and de-personalising any council response to neighbour complaints, councils will be able to achieve the twin aims of reducing the number of complaints that they receive and improving winter air quality within their jurisdictions.

Tackling domestic wood smoke emissions may seem to be a daunting undertaking for any council that has a large number of households who have operating wood heaters within their area. However, in reality the task may be a lot simpler than it appears to be.

Studies carried out in Armidale by Bullar & Hine[2] from the University of New England (UNE) found that 85% of the smoke emitted by a surveyed population was produced by just 15% of the wood burning households. This confirms an earlier estimate by J. J. Todd in 1997[3] that around 15% of all wood fires are likely to be operated incorrectly.

What this shows is that excessive wood smoke is not a problem inherently associated with the use of all wood heaters and open fires. It is, in fact a consequence of the misuse of a wood fire; through lack of maintenance, poor installation, uneducated operation practice or the burning of unsuitable fuel. The small percentage of high smoke emitting households that are the cause of most wood smoke complaints are also the main contributors to elevated levels of fine particle pollution in residential areas during winter.

Therefore, any Council that wants to proactively reduce domestic wood smoke pollution does not need to devote resources to try to change the behaviour of all households who have a wood fire. It is only necessary to identify the relatively small number of households who are not operating their wood fires properly and then motivate them to change their operating practices and, if required, remedy any installation or maintenance inadequacies.

A pilot program run by the Launceston City Council from 2002 to 2004, with funds provided by the Federal Government's *Air Pollution in Major Cities Program*, clearly showed that directly targeting high wood smoke emitting households with a combination of education and enforcement was highly effective in reducing wood smoke emissions. Of the 2126 highest emitting households identified in the city of Launceston during term of this program, 80% remedied their operating practice immediately on receipt of a notification that they were emitting excessive smoke. All except one of the remaining targeted households ceased to emit after receiving further contact that implied punitive legal action may be taken.

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[2] Hine, D.W. et. al. (2011). Comparing the effectiveness of education and technology in reducing woodsmoke pollution: A field experiment. *Journal of Environmental Psychology*, *Vol. 31 Issue 4 December 2011*.

[3] Todd J.J. (1997). Impact of Pollution Controls on Woodheater Emission Factors. In-house *Fuelwood Report No 59*, Centre for Environmental Studies, University of Tasmania, Hobart.

The objective of this current wood smoke reduction project is to facilitate the widespread adoption of the targeted education/enforcement model that was shown to be highly effective during the Launceston pilot program.

A report by Brendan Ling[4] on the Launceston program identified two major impediments that would prevent the use of this approach by most local governments. First, the cost of carrying out the wood smoke surveys to identify the high emitters, and then monitor the results of the interventions, was quite considerable and would be beyond the resources of most councils. Second, the delivery of education had some unintended outcomes, such as overreaction by householders, and in some cases the attempted delivery of education was met with stern resistance or hostility by the offending householder.

To accomplish the objectives of this current project the main impediments identified by the Launceston program would need to be resolved. Therefore, the two major aims of this project were identified as:

1. Develop an efficient method of identifying problem wood smoke emitters
2. Design and test an effective targeted education intervention strategy for high smoke emitting households

To achieve the first of these aims the FAA commissioned Kenelec Scientific Pty. Ltd. to construct the car based, fine particle analysis and recording system called *"SmokeTrak"*. The "*SmokeTrak"* system is a commercial adaptation of the Travel BLANkET system that was first developed by EPA Tasmania for use in their "*Burn Brighter this Winter*" Domestic Wood Smoke Management Program[5]. The "*SmokeTrak*" system uses a TSI Real Time DustTrak Aerosol Monitor to continuously measure $PM_{2.5}$ concentrations at street level. Readings from the DustTrak monitor are uploaded directly to a data logger provided by Pervasive Telemetry, which transmits the particle concentrations to a web based database via the mobile phone network.

Testing of the "*SmokeTrak*" system in Phase 1 of the project during the winter of 2013 demonstrated its capacity to effectively record and display street level wood smoke concentrations, at approximately individual household resolution. The system can be operated at any time, day or night, by a single person driving in a car at a reasonable speed. The automated data uploading, analysis and display capabilities of the Pervasive Telemetry service make the identification of high emitting households a cost effective and simple process, provided weather conditions are suitable. The system also provides a practical means of identifying localities within a shire that regularly experience high levels of wood smoke from the aggregated emissions from one or more high emitting households and/or as a result of the local topography.

[4] Ling, B. (2004). Targeted Education of Woodheater Users in Launceston. *Environmental Health Vol. 4 No. 4 2004*.
[5] EPA Tasmania (2013). "Burn Brighter This Winter" Domestic Smoke Management Program. Retrieved from http://epa.tas.gov.au/epa/burn-brighter-this-winter-2013

The development and subsequent successful field trial of the *"SmokeTrak"* system satisfied the first aim of this project.

To determine the best strategy for accomplishing a sustainable change in the smoke emitting behaviour of high emitting households, which is the second major aim of the project, it was decided to conduct a field trial of three different methods of engaging with the householder over two consecutive years.

Previous studies have shown that one of the main difficulties in establishing a behaviour change in high emitting households is the unwillingness of these householders to engage with authorities, or even accept the fact that they are emitting unacceptable amounts of smoke. It was decided to see if face-to-face wood heater operation education, when delivered by a non-government wood heater service professional who has been invited into the house, would be more effective than official health warnings, media publications, and community education events sponsored by Councils.

In Phase 2 of the project, carried out during the winter of 2014, 60 households were selected from those identified as being regular high emitters during the testing of the "*SmokeTrak"* system. Forty of the selected households were randomly allocated to receive a letter offering a free flue clean and safety check of their wood heater or fireplace.

Of the forty households that were sent a free flue clean offer, twenty households accepted the offer by contacting one of the listed service professionals to schedule a visit. Ten of the responding households were allocated randomly to receive an "enhanced" flue clean which involved analysis by the service provider on the likely cause of the excessive smoke emission plus advice on heater operating practice (Condition 1), the remaining ten were allocated to receive just a flue clean and safety check of the heating appliance (Condition 2). All of the flue clean interventions were completed by the end of the 2014 wood heating season. The 20 households that received the free flue clean offer but did not accept it were allocated into a third assessment group (Condition 3). The remaining 20 selected households were not contacted at all to create a Control group for the field trial.

During Phase 3 of the project all of the households in the study were surveyed regularly throughout the winter of 2015 to assess the effectiveness of the various interventions carried out the previous year. In early August 2015 eight households from the field trial who were still regularly emitting excessive smoke were sent a follow-up letter. This letter instructed the householders to cease their smoke emissions and advised them that they could be prosecuted under NSW Protection of the Environment legislation if they failed to act on this instruction. These householders were invited to contact Council to discuss their heater's emissions.

The results of the post-intervention monitoring (Phase 3) surveys showed that, compared to the Control, the targeted intervention program carried out during this project was highly effective in reducing the frequency of high smoke emissions.

- The households that received the "enhanced" flue clean intervention (Condition 1) showed considerable improvement, with eight of the ten households not emitting excessive amounts of smoke following the initial intervention. After the follow-up letter, only one household continued to emit excessively. This household would require further motivation to force a change in their wood fire operating behaviour.

- The households that received the free flue clean without the additional advice (Condition 2) also showed a marked improvement in their smoke emissions. Sixty percent the houses did not emit excessive smoke after the initial intervention. Both high emitting households in this group that were sent a follow-up letter stopped emitting immediately after receiving the letter.

- The households that received the free flue clean offer from council but did not accept the offer also showed a moderate reduction in their smoke emissions. Fifty percent of these (Condition 3) households stopped emitting excessively after receiving the flue clean offer however, some of this apparent reduction may have been due to variations in the weather conditions. Of the four households in this group who received the follow-up notification letter, three immediately ceased emitting. The one household that continued to emit excessively would require further stimulus to bring about a change in their operating practice.

- The Control group showed no significant change in their smoke emitting behaviour over the duration of this program, other than the expected variation in wood heater emissions due to changes in the weather.

In summary the face-to-face flue clean intervention program trialled during this program achieved a significant reduction in excessive smoke emissions for 95% of high emitting households. The program indicated that notifying householders about their excessive emissions can also be reasonably effective, especially when the initial notification is supported by a more forceful follow-up directive to households that continue to emit excessive smoke.

The proven success of the face-to face interventions tested during this project provides sound evidence that targeted education, combined with a notification of the potential for prosecution, will achieve a substantial improvement in the wood fire operating practices of high smoke emitting households.

The results of this project have clearly demonstrated that excessive domestic wood smoke emissions can be substantially reduced or eliminated by adopting the following methodology:

1. Use the "SmokeTrak" system to 'map' wood smoke concentrations and prioritise localities that have the worst winter air quality.
2. Use a combination of "SmokeTrak" readings and visual observation to identify households that regularly emit excessive smoke in the prioritised locality.
3. Contact local wood heater service professionals who are prepared to carry out in-house education and inspection where possible.
4. If necessary, request repairs or modifications be made to the high emitting wood heater or flue installation.
5. Monitor wood smoke emissions from the targeted households after intervention.
6. Where necessary, issue a letter demanding cessation of smoke emissions which raises the possibility of prosecution if the householder fails to respond.
7. Instigate proceedings against any recalcitrant emitters if required.
8. Use "SmokeTrak" to measure local area air quality improvement.

This suggested program is affordable because it can be carried out by a single staff member during the winter wood burning season. Operation of the "*SmokeTrak*" system is relatively straight forward and does not require any special skills or training. A complete "*SmokeTrak*" unit can be purchased or hired from Kenelec Scientific (www.kenelec.com.au). To ensure confidential access to, and security of the survey data, it is preferable if organisations carrying out a smoke reduction program establish their own account with Pervasive Telemetry (www.pervasivetelemetry.com.au), although this can also be arranged through Kenelec Scientific.

Any council or other organisation wishing to conduct a wood smoke reduction or abatement program can be confident in its success if the protocol outlined above is followed.

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INTRODUCTION

As the national body representing the commercial firewood supply chain, the Firewood Association of Australia Inc. (FAA) seeks to promote the environmental attributes of firewood as a carbon neutral[6], low cost, source of renewable bioenergy for domestic heating. An important part of this overall objective is to minimise any negative environmental or social impacts that may be associated with burning firewood.

Domestic wood smoke can be a real and significant problem for residents who are within close proximity to an incorrectly operated heater, or who share a common air-shed with incorrectly operated heaters. The impact of a single, badly operated wood heater can be magnified where topographic and climatic conditions combine to confine the smoke within a locality. Residents who have a nearby neighbour that burns unacceptable material in their fireplace, such as treated, painted or contaminated wood, old rail sleepers, unseasoned wood or even household refuse, are often the ones who will lodge a complaint with their local council.

Studies carried out by the University of New England (UNE) in Armidale by Bullar & Hine[7] in 2011 found that 85% of the smoke emitted by a surveyed population was produced by just 15% of the wood burning households. This finding supports an earlier estimation made by John Todd of Eco-Energy Options[8] that around 15% of all wood fires are likely to be incorrectly operated. What this shows is that nuisance wood smoke is not actually a problem inherently associated with the use of wood heaters and open fires. It is a direct consequence of their incorrect use, lack of maintenance, poor installation or the use of unsuitable fuel. The small percentage of high smoke emitting households that are the cause of most wood smoke complaints are also the main contributors to elevated levels of fine particle pollution in some residential areas during winter.

Clearly the most efficient way for councils to minimise complaints about domestic wood smoke, and at the same time improve winter air quality, is to target the small percentage of wood fires that are creating most of the problem.

Previous research[9] carried out in this field indicates that a significant reduction in the number of households that emit high levels of wood smoke can be achieved by directly targeting the operators of these heaters with a combined education and enforcement intervention strategy.

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[6] Paul, K., Booth, T., Elliot, A., Jovanovic, T., Polglase, P., & Kirchbaum, M. (2003). Life Cycle Assessment of Greenhouse Gas Emissions from Domestic Woodheating. Prepared for the Australian Greenhouse office by CSIRO Forestry and Forest Products.

[7] Hine, D.W. et. al. (2011). Comparing the effectiveness of education and technology in reducing woodsmoke pollution: A field experiment. *Journal of Environmental Psychology, Vol. 31 Issue 4 December 2011*.

[8] Todd J.J. (1997) Impact of Pollution Controls on Woodheater Emission Factors. In-house *Fuelwood Report No 59*, Centre for Environmental Studies, University of Tasmania, Hobart.

[9] Ling, B. (2004). Targeted Education of Woodheater Users in Launceston. *Environmental Health Vol. 4 No. 4 2004*.

However, the researchers who conducted these studies identified two major limitations to this method of domestic wood smoke control.

Firstly, identifying the high emitting households that need to be targeted for intervention is problematic. Smoky chimney surveys and visual assessment of smoke plumes are a labour intensive and therefore costly exercise. The location of houses emitting smoke plumes can be reliably established in daylight hours but is difficult at night, therefore smoky wood fires that are not normally operated during the day can remain un-identified.

Secondly, establishing contact to effectively engage with the high emitters can be challenging. Often these people are highly resistant to messages about the health impacts of wood smoke. Many refuse to accept that their heaters are emitting unacceptable or excessive amounts of smoke. Most believe they have a right to burn wood for heating and are antagonistic to any bureaucratic attempts to influence or control what they consider to be their private behaviour.

In 2013 the FAA, in collaboration with The Hills Shire Council in NSW, commenced a Wood Smoke Reduction Project. The overall objective of the project was to determine the most cost effective and efficient method for the control and minimisation of domestic wood smoke. The project had two major aims:

1. Develop a cost effective method for identifying problem wood smoke emitters
2. Design and test an efficient intervention strategy for high smoke emitting households

In 2013 the FAA purchased a '*SmokeTrak*' mobile smoke detection system. The '*SmokeTrak*' system has been designed and developed by Kenelec Scientific Pty. Ltd. to enable the efficient and accurate recording of ultra-fine particulate levels at street level. This system was field tested throughout July and August 2013 in The Hills Shire.

The "*SmokeTrak*" system produces high resolution, real time mapping of fine particle concentrations. The system can be operated during the day or night by one person in a car driving at 30-60 kph or more. Data is automatically uploaded from the mobile system onto a web site for analysis via the mobile phone network.

In 2014, using the '*SmokeTrak'* supported by visual observation, 60 high wood smoke emitting households within The Hills Shire were selected for the conduct of a field trial to assess the effectiveness of three different targeted intervention strategies.

The effectiveness of the three intervention strategies was assessed throughout the winter of 2015 by repeated observation and use of the "SmokeTrak" system.

BACKGROUND

The firewood industry in Australia is becoming increasingly concerned about actions that are being taken by some local councils and state environmental agencies to restrict or ban the use of wood fires. As a result of these concerns, as well as an increased focus on domestic wood smoke by environmental health lobby groups and government bodies such as the Standing Council on Environment and Water, members of the Firewood Association of Australia decided to dedicate resources to developing and promoting a practical and commercially acceptable solution to the problem of smoke from domestic wood fires.

Contact with councils across Australia has indicated that dealing with wood smoke complaints is not a major part of the workload of most environmental officers. Nevertheless, almost all councils located in areas where wood heaters are regularly used receive some complaints from residents each year about domestic wood smoke.

Complaints about wood smoke from residents is undoubtedly one of the main drivers for those local governments across Australia who are now actively discouraging the use of firewood for domestic heating. In general, Councils have attempted to address this issue by applying restrictions on approvals for new wood heater installations and by trying to reduce the number of operating wood heaters in the community. Mostly they have done this by setting tighter controls and restrictions over the positioning of flues and by promoting the use of non-renewable, carbon polluting, alternative heating options such as 'natural' gas and coal fire generated electricity.

It is apparent that the level of concern that any particular Council has about domestic wood smoke is closely related to the number of complaints that they receive annually. Councils who only receive a few complaints each winter generally do not regard domestic wood smoke as a significant problem. When a Council receives numerous complaints each winter, wood smoke is usually considered to be an important issue.

In some local government areas topography can play an important role in the perception of the seriousness of domestic smoke pollution. When smoke becomes trapped in a valley or natural depression under a winter temperature inversion, smoke from an individual, high-emitting chimney can accumulate and spread to affect a whole community, instead of just a few immediate neighbours. This can magnify the perception of smoke pollution and lead to more complaints and increased pressure on councils to resolve the problem.

From an environmental health perspective, government agencies are becoming increasingly concerned about the potential negative health impact of fine particle pollution. According to the National Pollutant Inventory (NPI)[10], smoke from domestic wood heating only makes up 1.4% of total fine particle pollution in Australia. The majority of fine particles are generated by bushfires, fuel reduction burns, agricultural burns and diesel and petrol engine exhaust emissions as well as dust from mines, roads and farming operations.

Given the relative small contribution made by domestic smoke to particle pollution nationally, the targeting of wood heating by government agencies may seem illogical; however, there are sound reasons for this focus.

Realistically, there is no way that governments can control smoke from wildfires, forest fuel reduction and other 'landscape' sources. This means that if they are going to take action to protect the health of their constituents, then they can only target 'anthropogenic' sources of emissions such as wood heaters, industry, engine emissions and mining operations. In addition, much of the particle pollution from the biggest emitting sources occurs in remote or sparsely populated areas. When domestic wood smoke is emitted in densely populated areas such as cities and towns, there is an increased likelihood that residents will be subjected to unacceptably high concentrations of fine particles.

In 2011 the Council of Australian Governments (COAG) identified air quality as a *Priority Issue of National Significance* and agreed that the COAG Standing Council on Environment and Water (SCEW) would develop a National Plan for Clean Air to improve air quality, and community health and wellbeing. The first stage of the National Plan for Clean Air focuses on fine particles and this research program aligns with the initial action item identified by SCEW, which is aimed at reducing the emissions from wood heaters. In December 2015 the federal and state and territory governments signed the National Clean Air Agreement which provides a framework for action to address air quality problems in Australia. One of the activity streams in the initial work plan under the Agreement is aimed at reducing the emissions from wood heaters.

At a state level, and now at the federal level, through the National Plan for Clean Air and the Clean Air Agreement, the policy direction that has been taken to address domestic wood smoke has been mainly targeted at lowering the rated emission level of new, controlled combustion heaters.

Although this direction should, in theory, result in a gradual reduction of wood heater emissions over time, it is unlikely to achieve a noticeable reduction in problem smoke emissions in the short term because the typical controlled combustion heater has more than a 30-year life span. There is also a risk of failure in this approach if there is a significant increase in the number of households that elect to use wood for space heating, especially if people purchase cheaper, uncertified makes of heaters.

[10] NPI 2011, 2010/2011 data within Australia – Particulate Matter 10 μm from All Sources. National Pollutant Inventory, Department of Sustainability, Water, Population and Communities.

There is already some evidence to suggest that wood heating is regaining popularity, partially as a result of increasing domestic gas and electricity prices but there is also a renewed appreciation of the aesthetic appeal of a wood fire. Many overseas countries are now actively promoting wood heating as a means of lowering their carbon emissions and decreasing the demand on their non-renewable energy resources through renewable heat incentive programs. If Australia is to follow the trend in these countries, then an increase in wood heater usage is inevitable.

The simplest solution to these concerns about domestic wood smoke would be to ban all wood fired heating but this is not a realistic option. In 2011, 10% of all Australian households used wood fires as their main source of energy for home heating – approximately the same proportion as in 2005 and 2008[11]. In rural and regional areas in the southern half of Australia the percentage of households that rely on wood fires for their winter heating is far greater.

In regional cities that do not have access to 'natural' gas, up to 80% of households have wood fires and in rural areas close to 100% of farmhouses have a wood fire. In Tasmania, where only limited areas have access to gas piped across Bass Straight from the mainland, the percentage of households that rely on wood heating is also considerably larger than in other states.

Burning firewood is beneficial in several ways. It is comparatively inexpensive, relative to alternative home heating options such as electricity and gas. It is readily available in many communities in Australia, and it produces fewer greenhouse gas emissions than all other major sources of heating such as gas and coal-generated electricity (Paul et al., 2003[12], Polglase et al., 2012[13]).

Many people have a strong affection for wood fires. This is evidenced by the increasing popularity of wood fires around the world. In many cold climate countries, where whole of house heating is required in winter, homes frequently have a wood fire in addition to their main household heating appliance. Wood fires are highly valued in these countries because they provide a source of radiant heat for instant warming and drying, as well as a pleasing ambience. It is often said that a wood fire 'cheers the room' and many commercial establishments feature wood fires to attract customers in winter.

Any moves to prohibit the use of domestic and commercial wood fires would most certainly be met with strong opposition from the community.

[11] Australian Bureau of Statistics 1301.0 – Year Book, Australia 2012

[12] Paul, K., Booth, T., Elliot, A., Jovanovic, T., Polglase, P., & Kirchbaum, M. (2003). Life Cycle Assessment of Greenhouse Gas Emissions from Domestic Woodheating. Prepared for the Australian Greenhouse office by CSIRO Forestry and Forest Products.

[13] Polglase, P., Paul, K., Meyer, M., (2012). Comment. *Atmospheric Pollution Research 3 (2012) 258-259.*

While it is accepted that every wood fire will at times generate some smoke; if all wood fires were producing unacceptable levels of smoke, councils would be inundated by complaints every winter, which is not the reality. Most residents will tolerate brief exposure to smoke from a neighbour's wood fire during start up. Complaints about excessive smoke are sometimes motivated by a dispute between neighbours over other issues, however most complaints are generated by a prolonged exposure to unacceptable levels of wood smoke, either from a known high emitting neighbour, or simply within a locality.

Several studies have been carried out in Armidale by the University of New England (UNE) team of Professor Don Hine and Dr Navjot Bhullar on the psychological profile and behaviour of high wood smoke emitting households. In addition, two 'targeted education' programs have been carried out in Tasmania in recent years. These studies have indicated that it is in fact possible to achieve a lasting change in the way that wood heaters are operated, and to thereby achieve a substantial reduction in problem smoke emissions, by applying appropriate psychological interventions to the operators of high smoke emitting fires.

Importantly, the Armidale studies by the UNE team found that education concerning the health risks associated with wood smoke was not effective in motivating a change in heater operation practices by high wood smoke emitters[14].

The UNE team also investigated potential factors for motivating high smoke emitters to change their behaviour. This study investigated several key psychological factors contributing to public support for policies designed to mitigate smoke from wood heaters.

Many councils would like to reduce the number of wood smoke nuisance complaints that they have to deal with and at the same time improve the winter air quality within their local jurisdiction. However, most believe that the resources that would be required to achieve a meaningful reduction in wood smoke would be excessive and unjustifiable within the budgetary constraints faced by local governments.

The intended outcome of this project is to develop a 'toolkit' of simple and affordable smoke control measures, materials and methods that can be implemented by any Council wanting to reduce smoke from domestic wood heaters in their local area.

[14] D Hine, A Marks, N Bhullar, C Davies & J Scott. (2012). The Affect Heuristic and Public Support for Three Types of Wood Smoke Mitigation Policies. University of New England, School of Behavioural Cognitive and Social Science.

What Causes Wood Smoke?

When wood burns it does so from the outside of the piece to the middle in various stages according to its temperature. In the first stage (up to 200°C) some gases are emitted and the wood chars but solid wood does not ignite. In the second stage (200° – 280°C) the emitted gases mix with oxygen and will ignite, provided there is sufficient external heat. In the third stage (280° – 500°C) flaming self-sustained, exothermic combustion occurs outside the wood when the emerging gases and tars are able to mix with sufficient oxygen. One half to two thirds of the heat of combustion of wood is liberated in this stage by the flaming gases. In this stage of combustion, the gases coming from the heated wood effectively cover the wood surface and exclude oxygen, which prevents the charcoal underneath from burning. When the emission of these gases eases, oxygen is able to reach the surface of the wood and the charcoal ignites. During this final stage of combustion, above 500°C the charcoal glows red and at 1000°C it burns freely but with little visible flame.

If there is insufficient heat or inadequate oxygen, combustion of the gases emitted during the second and third stages of combustion will be incomplete. These unburnt gases and tars will condense as they cool to form creosote and the fine particles that we see as smoke.

How Do You Operate a Wood Fire Without Emitting Excessive Smoke?

Avoiding excessive smoke is not hard, provided that the wood is dry. The main way to stop smoke is to ensure that there is adequate oxygen reaching the wood during its early stages of combustion, when gas release is at its maximum. This can be achieved in slow combustion heaters by having the air inlet vents wide open and also ensuring that there is an adequate draft up the flue or chimney. A blocked flue will restrict air flow to the fire and prevent complete combustion. By initially burning small pieces of wood or kindling that have been arranged to allow air to reach all surfaces, a hot fire will be established quickly. This permits the wood to rapidly reach the temperature required for stage three exothermic combustion and also ensures that sufficient oxygen (air) can get to the emitting gas to facilitate complete combustion. As the fire gets hotter the size of the pieces of wood can be increased without causing the temperature of the fire to drop below third-stage combustion temperature. Once the wood has reached final-stage temperatures there is little gas released and therefore not much smoke, so large pieces that will burn more slowly and emit heat over a longer time can be safely added.

In summary when lighting a fire or adding more wood to an existing fire that has died down:

- Get as much air (oxygen) into the fire as quickly as possible.
- Progressively increase the size of the firewood.
- Arrange the wood so that plenty of air can get to all sides.
- Only reduce the air intake and close the fire down when it has a good bed of glowing red coals.

Some people think that by closing the air vent straight after adding wood they will save money. But all this does is create smoke, reduce heat recovery, upset the neighbours, and eventually it will block the chimney. If air flow in the flue is blocked by creosote, or a build-up of soot on the baffle is blocking air flow, then the fire will not be able to get sufficient air (oxygen) to burn properly.

The Chemistry of Wood Smoke[15]

The combustion process for wood is different to other solid, liquid or gaseous fuels. An external heat source is required to start the process of drying and thermal decomposition of wood. At temperatures of around 200° – 280°C, exothermic reactions (i.e. giving off heat) commence and the decomposition process can become self-sustaining. This process of thermal decomposition causes chemical changes in the complex organic molecules that constitute lignin, cellulose and hemicellulose. Organic gases are released, leaving a carbon-rich solid residue. The carbon (charcoal) burns as a result of surface reactions (with little gas release) leaving a residue of ash. The ash content of wood is low, typically 0.5% by weight of dry matter (slightly higher for bark). The energy content of wood does not vary much from one species to another; eucalypt hardwoods typically release 19 MJ/kg and softwoods about 21 MJ/kg, provided combustion is complete.

As noted above, incomplete combustion of the volatiles released from the wood is what creates smoke. Volatile organic compounds (VOCs) are released from wood at temperatures as low as room temperature, but substantial, rapid release only begins when exothermic reactions commence. The volatiles are a complex mix of combustible gases. The ignition temperature of the gas mix is generally around 500°C. If they are not burnt, many of the volatiles that are released from wood during combustion will condense to form fine particles when cooled to near-ambient temperatures, creating smoke.

Wood-smoke has a complex chemical composition. It consists of a mix of low molecular weight carbon based gases and many large molecular weight organic compounds in the particles. The main polluting gas emitted by wood heaters and open fireplaces is carbon monoxide (CO).

Other gases emitted include methane (CH4), ethane, propane and other low molecular weight organic gases. Generally, other 'priority air pollutant gases' such as sulphur dioxide (SO2) and oxides of nitrogen (NOx) are only emitted in very small quantities and are not considered a problem from wood heaters. The particles (or condensed droplets of tars) are made up of a complex mix of organic compounds, with the chemistry changing depending on combustion conditions in the heater and the chemical composition of the wood.

[15] Todd, J.J. (2003). Wood-Smoke Handbook: Woodheaters, Firewood and Operator Practice. For The Natural Heritage Trust, commissioned by Environment Australia and The NSW Environment Protection Agency.

PREVIOUS RESEARCH

The Launceston Targeted Education Program

The use of targeted education as a means of achieving a behaviour change in high smoke emitters was tested during a pilot program run by the Launceston City Council from 2002 to 2004. This program operated under the Federal Government Air Pollution in Major Cities Program which provided $2.05 million in funding to improve winter air quality in Launceston. A report by Brendan Ling[16] on the Launceston targeted education program was published in the *Journal of the Australian Institute of Environmental Health*

During the three winters that this pilot program operated; 2,126 high smoke emitting households were subjected to targeted education aimed at reducing their wood smoke emissions. Once a high emitting household was identified, initial contact was made by a notification card being placed in the letterbox. This card advised the householder that their chimney was producing unacceptable levels of smoke at the times specified on the card. The card also provided an invitation for the householder to contact the project team for assistance and advice on reducing smoke emissions.

The targeted household was then observed for smoke three to four weeks after the initial contact. If excess smoke was observed again, an addressed 'First Warning' letter was sent to the householder. These letters warned that a $200 on-the-spot fine could be issued under Tasmanian legislation. The letter also warned that an abatement notice could be issued, legally requiring the user to cease emitting smoke. During the entire program a total of 356 'First Warning' letters were sent.

If smoke was observed on a third occasion, a 'Final Warning' letter was sent to the householder. This letter informed the resident that, if further observations of excess smoke were made, then action would be taken against them. A total of 27 Final Warning letters were sent out during the program. At the end of the pilot program late in 2004 no fines had been issued however one abatement notice was served.

This pilot program provided strong evidence that direct contact through targeted education can be highly effective in achieving a change of heater operation practice. Over 80% of households stopped excessive smoke emissions after receiving a card in the letterbox. Just over 1% of smoke producing households required the threat of punishment to motivate a change in their smoke emitting behaviour. It appears as though the majority of those receiving the card in their letterbox changed their behaviour without further contact however, because there was no control in this program it is possible that some of these high emitters could have stopped emitting during the period of observation as a result of external factors, such as the weather conditions.

[16] Ling, B. (2004). Targeted Education of Woodheater Users in Launceston. *Environmental Health Vol. 4 No. 4 2004*.

Very few residents accepted the invitation to contact the research team for advice on heater operation. This suggests that many high emitters are simply unaware that they are emitting excessive amounts of smoke or that their smoke emissions are socially unacceptable.

For the pilot program, smoke plumes were visually assessed as being either, excessive, moderate, or acceptable by comparing them to the photos on the Environment Australia "*Check your chimney*" fridge magnet as shown below.

Despite the obvious success of this program, the reason that Launceston City Council, and other councils around the country, are not using targeted education as a way to solve domestic wood smoke problems can probably be attributed to the main limitation identified in the Launceston pilot study - the cost of conducting the smoke surveys, which was considerable.

Field assessments had to be carried out during daylight hours only, limiting the number of households that could be assessed and requiring a large field team of assessors. Some attempts to visually identify smoke at night were made, but these were soon abandoned as impractical. Using a team of two full time employees and two, part-time volunteers it was possible to cover about one suburb per day. This allowed the entire city of approximately 67,000 houses to be surveyed every three to four weeks. The record of observations was then entered into an Access database which also proved to be a highly time consuming process, taking as long as the actual surveys.

The large demand on human resources that would be required to repeat this program in other areas, especially in larger cities over any extended length of time, would almost certainly dissuade most local councils from adopting this type of program.

The survey team also found that the visual appearance of smoke varied depending on the background, making it necessary to view smoke plumes from a number of angles to achieve an accurate assessment. This subjective assessment of smoke plumes left the team open to challenges by some recipients of the cards who simply stated that their heater 'does not smoke'!

In the conclusion of the report on the Launceston pilot study, it is stated that the apparent success of the program is primarily related to the personal nature of the cards and letters. It is thought that this results in greater behaviour change than the usual broad scale media and community engagement that has been the mainstay of most smoke reduction programs run in the past by councils and State Environmental Protection Authorities.

EPA Tas – *"Burn Brighter This Winter"* Domestic Wood Smoke Management Program[17]

In 2012, the EPA Division of the Tasmanian Department of Primary Industries, Parks, Water and Environment, in collaboration with the Launceston City Council and the Hobart City Council commenced a Domestic Wood Smoke Management Program called *"Burn Brighter This Winter"*. The first phase of this program was focused on two residential areas containing approximately 500 houses each, one in East Launceston and the other in West Hobart. For Phase 2 of the program in 2013 the targeted areas were Geeveston in the Huon River valley and Hadspen in the Meander River valley. Phases 3 and 4 of the program were conducted in Longford in the Northern Midlands Council area.

This ongoing program has two main objectives;

- increasing community awareness of domestic air quality issues; and
- monitoring air quality in defined focus areas

The community awareness activities consisted of presentations, information documents, media articles, a web site, community forums and letters to residents. These were produced in accordance with a communications strategy that was developed at the commencement of the project.

Air quality monitoring in the focus areas was carried out using the static Base-Line Air Network of EPA Tasmania (BLANkET) stations as well as through a novel, car based system developed by the EPA team called the 'Travel BLANkET'. This car based monitoring system was developed by the EPA's Air Quality Division to increase the spatial area over which ground level $PM_{2.5}$ concentrations could be directly measured, and to provide greater flexibility in the times at which this data could be collected. The 'Travel BLANkET' system consists of a TSI 8533 Dust Trak TM optical particle counter, inlet heater, modem and associated componentry in a portable case and is GPS enabled. The 'Travel BLANkET' provides near instantaneous mapping of survey routes and $PM_{2.5}$ concentrations, which are uploaded onto the EPA's internal web site. Several 'Travel BLANkET' smoke monitoring surveys were conducted in each of the focus areas.

[17] EPA Tasmania (2013). "Burn Brighter This Winter" Domestic Smoke Management Program. Retrieved from http://epa.tas.gov.au/epa/burn-brighter-this-winter-2013

Some of the reported benefits of the 'Travel BLANkET' system were:

- smoke concentrations are objectively measured by the Dust Trak instrument, avoiding the subjective visual assessment of plumes
- smoke plumes can be detected at night when most fires are in use
- the system operates in a car travelling at 20-60 kph, allowing a large area to be surveyed
- the system can be operated by one person
- smoke readings and GPS co-ordinates are uploaded automatically onto a database

Following the initial use of the 'Travel BLANkET' system for air quality monitoring during the 2012 season, the EPA was able to make the following conclusions:

- Effective car based monitoring of smoke can be conducted even in a high density inner urban residential area.
- Direct measurement of individual smoke plumes in an inner urban area is possible, at least under some circumstances.
- In some cases, the presence of an excessively smoky chimney was first identified from repeated high $PM_{2.5}$ measurements in a given location.

During the winter of 2012 both 'Travel BLANKET' smoke measurement surveys and visual searches for chimneys that were considered to be producing excessive smoke, were carried out in the study areas. From these surveys a total of 62 houses were identified as having excessively smoky chimneys, 18 in Launceston and 44 in West Hobart.

All of the West Hobart houses had a notification card placed in their letterbox, similar to the 2002-4 Launceston targeted education program referred to above. These cards informed residents that they were emitting excessive smoke. Thirteen of the identified houses in West Hobart were observed to be emitting smoke a second time and were sent a letter containing further advice concerning wood heater operation. Fifteen of the Launceston houses were sent this same letter after just one observation. The reason for this is that it was assumed that these Launceston houses had, in all likelihood, already been given a notification card during the 2002-4 program. Of the houses sent these letters, 26 were observed to be emitting once more, thirteen were observed a second time and nine on three or more occasions. The nine houses that had persistent smoke emissions at the completion of the surveys were issued with a letter requesting they contact the EPA to arrange a "house visit". Only one such house visit was conducted.

Although the first year of this program could be considered a reasonable success, some valuable conclusions were made. Similar to the 2002-4 Launceston targeted education program, simply notifying residents that they are producing smoke appeared to be an effective way to achieve behaviour change for some households, although there is some doubt about the efficacy of this approach. The Tasmanian EPA team carried out detailed smoky chimney surveys of households in Hadspen and Geeveston in 2013[18]. These surveys recorded emissions both before the notification was issued to 30 of the highest emitting households in these two towns, and after the notification. The surveys indicated that the notifications stimulated little change in the smoke emitting behaviour of the worst emitting households, which casts some doubts on the amount of improvement claimed in the report on the Launceston program[19].

Attempts to engage with recalcitrant smoke emitters by inviting them to contact the EPA for a "home visit" were generally unsuccessful. A better way to engage with these "hard cases" is clearly needed. Widespread community engagement that is focussed on the health impacts of wood smoke can pre-sensitise residents to the issue, leading to more smoke nuisance complaints. It may also harden the attitude of some emitters, making them less amenable to a change in behaviour. Public notices about the smoke surveys that were conducted as a part of the program elicited some highly negative, and occasionally threatening responses from the community.

The programs conducted during the winters of 2014 and 2015 in Longford were focussed entirely on raising community awareness of the health impacts of elevated wood smoke levels.

Visible plume search activities were undertaken on four nights during the 2014 phase of the project in Longford. A total of 128 'excessive smoke plumes' were logged from individual residences on these four nights. Nineteen residences appear in the records on two or more occasions. Conducting visual plume searches in Longford was initially found to be a more difficult task than had been the case in Hadspen or Geeveston in 2013. The much bigger Longford residential area, and often the lack of easily identifiable house numbers, meant that maps and other information were consulted more frequently, slowing the process.

Foggy weather on two nights also reduced the contrast between plumes and the background atmosphere. As a consequence, a defined group of households identified as emitting excessive plumes of smoke on multiple occasions was not established, and a targeted intervention similar to that undertaken in the 2012/13 Burn Brighter project was not implemented.

[18] EPA Tasmania (2014). BLANkET Technical Report 27. A review of Tasmanian data 2013. Retrieved from http://epa.tas.gov.au/epa/document?docid=1519.
[19] Ling, B. (2004). Targeted Education of Woodheater Users in Launceston. *Environmental Health Vol. 4 No. 4 2004*.

Analysis of the data from the Longford station that is monitoring ambient concentrations of $PM_{2.5,}$ shows that in 2014 there was an increase in the number of calendar-day-averaged $PM_{2.5}$ values above the Air NEPM advisory reporting standard of 25 µg m^3. The number of calendar-day-averaged $PM_{2.5}$ values above the Air NEPM standard increased from 46 days in 2013 to 57 days in 2014. Analysis indicates that cooler, calmer meteorological conditions in Longford during the 2014 winter were the main cause of the increase. The monitoring data leads to the conclusion that the Burn Brighter This Winter program in Longford was not accompanied by an improvement in winter air quality.

The Armidale Wood Smoke Reduction Program.

In 2009 a team led by Professor Don Hine from the University of New England (UNE) started a program of research funded by an ARC Linkage Grant (LP0883389). As part of the research program, the team conducted a field experiment to assess the effectiveness of education and technological innovation in reducing air pollution generated by domestic wood heaters. The results of this experiment indicated that the households that received an education package as well as those that received a *Smart Burn* canister (technology) significantly reduced their household smoke emissions. A paper describing this field experiment by Hine, Bhullar et al. (2011) was published in the *Journal of Environmental Psychology*[20]. The main finding from this experiment was that the effect of education on smoke emissions reduction was mostly due to improved wood heater operation. That is, exposure to an education intervention led to significantly better operation practices, which in turn was associated with significant reduction household wood smoke emissions.

In 2010, the team implemented a Community Based Social Marketing (CBSM) campaign focusing on the negative health effects of wood smoke, and best practices in wood heater operation and firewood management/purchase. It was found that the CBSM campaign was associated with a significant increase in health risk perceptions about wood smoke and improved wood heater operation practices. However, $PM_{2.5}$ air quality monitoring indicated that overall wood smoke pollution levels in Armidale did not improve as a result.

This finding suggested that a broad-based community campaign can be strengthened by a more targeted approach comprising face-to-face demonstrations of wood heater operation and wood storage practices.

Subsequent analysis of households that participated in the 2009 field experiment revealed that the percentage of participating households that consistently emitted high levels of smoke during the monitoring period was quite low (around 15%)[21]. This suggests that the majority of householders in Armidale operate their wood heaters in a responsible manner.

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[20] Hine, D.W. et. al. (2011). Comparing the effectiveness of education and technology in reducing woodsmoke pollution: A field experiment. *Journal of Environmental Psychology, Vol. 31 Issue 4 December 2011*

[21] Bhullar, N. & Hine, D.W. (2012). *Summary of Main Findings*, ARC linkage Project LP0883389. Unpublished communication.

It also indicates that targeted education may prove to be a more cost effective option for reducing domestic wood smoke than community-wide interventions.

Furthermore, a survey of Armidale residents carried out by the UNE team[22] found that there was a divergence of views about the magnitude of the city's air quality problem and what, if anything, local government should do to address it. A substantial number of residents did not view wood smoke as a significant health threat, a view that is somewhat at odds with the scientific literature. Amongst those who recognise the threat, not all agree on the most appropriate policy response. Some residents favour public education about proper wood storage and wood heater operation, whereas others have argued for incentives for wood heater upgrades and replacements, fines for excessive emissions, or restrictions on when and where wood can be burned. In line with this research, community members with a strong positive emotional attachment to wood fires tended to perceive the benefits of wood burning to be high and the costs and health risks to be low. It is not surprising that individuals with this type of profile did not view wood smoke as a problem and were opposed to the introduction of policies that would threaten an activity that they valued and enjoyed and, according to their beliefs, posed little health risk.

This study shows why simply informing the wood burning segment of the community about scientific evidence linking health problems to wood smoke exposure is unlikely to be effective.

Policies involving public education or rebates/discounts for households wishing to upgrade their wood heaters or implement technological solutions to reduce emissions were broadly supported by all segments of the community. This support was regardless of whether they held positive or negative affective associations and risk-benefit cognitions about wood heating. Interestingly, these 'public friendly' policies were even supported by segments of the community who did not believe that wood smoke levels in Armidale posed a significant health risk, and did not accept that the community had a wood smoke problem.

Such policies attempt to reduce overall levels of wood smoke emissions without placing any legal restrictions on wood burning. Although wood heater users may be asked to modify their behaviour and/or be encouraged to adopt technological solutions to reduce emissions, these policies contain no punitive component for non-compliance. Nor do they pose any threat that the perceived "right to burn wood" would be withdrawn. In short, these policies appear to be widely acceptable given that they address the problem (at least for those individuals who perceive wood smoke pollution to be a problem), and preserve residents' individual freedom to heat their homes as they see fit.

[22] Hine D.W., et. al. (2012). The Affect Heuristic and Public Support for Three Types of Wood Smoke Mitigation Policies. Unpublished.

In 2012, the UNE team received a NSW Environment Trust Grant to trial a new field experiment based on 'Social Norms' theory. This study evaluated whether providing heavy smoke emitting households with feedback that their smoke emissions exceed the neighbourhood norm would be more effective than providing generic information about the negative health impacts of wood smoke pollution, which is a practice that is currently being employed by the Armidale Dumaresq Council (ADC).

The preliminary findings of this study found that both a "standard letter" and a "friendly letter" significantly reduced smoke emissions. The "standard letter", which is used by the ADC following wood smoke complaints, informed households about the health impacts of the fine particulates in wood smoke. The letter notifies the householder about their excessive wood smoke emissions and provides generic guidance on where to obtain further information about correct wood heater operation and firewood management practices. It also contains a warning about the legal ramifications of not reducing their smoke emissions. The "friendly letter" provided feedback about the household's smoke emissions exceeding the neighbourhood norm along with information on key practices that help to reduce wood smoke pollution.

METHODOLOGY

After canvassing a number of councils in the Sydney Greater Metropolitan Region (GMR), The Hills Shire Council agreed to participate as a partner with the FAA in a domestic wood smoke reduction project. The Hills Shire was looking for a more proactive way to improve winter air quality, instead of just reacting to complaints from residents. The number of wood smoke complaints received annually by the Council is not large, but there were known "hot spot" areas within the Shire that could be targeted for this project. The Council provided maps and records to assist with the experimental design, as well as the skilled resources to assist with the intervention/education phase of the project.

The Hills Shire is a large and diverse local government area located in north-western region of greater Sydney. At the time of this project The Hills Shire area covered 401 square kilometres and stretched from North Parramatta in the South to Wiseman's Ferry on the Hawkesbury River in the North. According to the 2011 census, The Hills Shire had a population of 169,872, but with a population growth at nearly double the national average the Shire's population is rapidly increasing. Of the Shire's 27 suburbs, those in the south are mainly made up of medium density separate residences and low-rise apartments. To the north, semi-rural properties are the norm, but new residential subdivisions are gradually expanding to the north and west. The median weekly income of residents within The Hills Shire is approximately 150% higher than the national average. Firewood suppliers who are members of the FAA report that The Hills Shire is by far the largest single market area for firewood sales in the Sydney metropolitan area.

Field work for the project was carried out by staff from the FAA's contracted management company QA Pty Ltd.

Phase 1 Project Activities (2013)

Identifying high emitting households

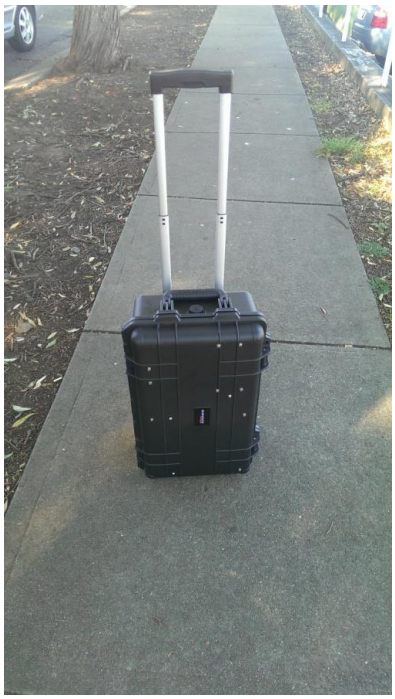
The successful use of the Travel BLANkET car based smoke detection system by the Tasmanian EPA team for their 2012 *Burn Brighter This Winter*[23] program showed the potential of this type of system for identifying high smoke emitting households. Accordingly, in March 2013 the FAA commissioned Kenelec Scientific Pty Ltd to design and build a similar system for use in this project.

Kenelec Scientific Pty Ltd are the importers and distributors of the Dust Trak laser based airborne particle monitor that is the "heart" of the Travel BLANkET system developed by EPA Tasmania. Kenelec have a highly skilled team of technical staff who were able to refine and simplify the system developed by EPA Tasmania, and make it a "stand alone" commercially available unit that can be used by anyone, anywhere in Australia.

The original system built by Kenelec, called *'SmokeTrak',* is shown in the pictures below. The system consists of, clockwise from the top right: A Pervasive Telemetry Agent G2 data logger and 3G network web interface, a $PM_{2.5}$ in line filter, a TSI 8530 Real Time Dust Trak Aerosol Monitor fitted with an auto zero module, a 12-volt power supply unit with back up battery, a Samsung Galaxy Tablet PC, and a GPS sensor.

[23] EPA Tasmania (2013). "Burn Brighter This Winter" Domestic Smoke Management Program. Retrieved from http://epa.tas.gov.au/epa/burn-brighter-this-winter-2013

As shown below, the system fits neatly into a sturdy plastic travel case which can be taken on board aircraft as carry-on luggage.



The case sits securely on the front passenger seat of a car when the seat is in the forward position.

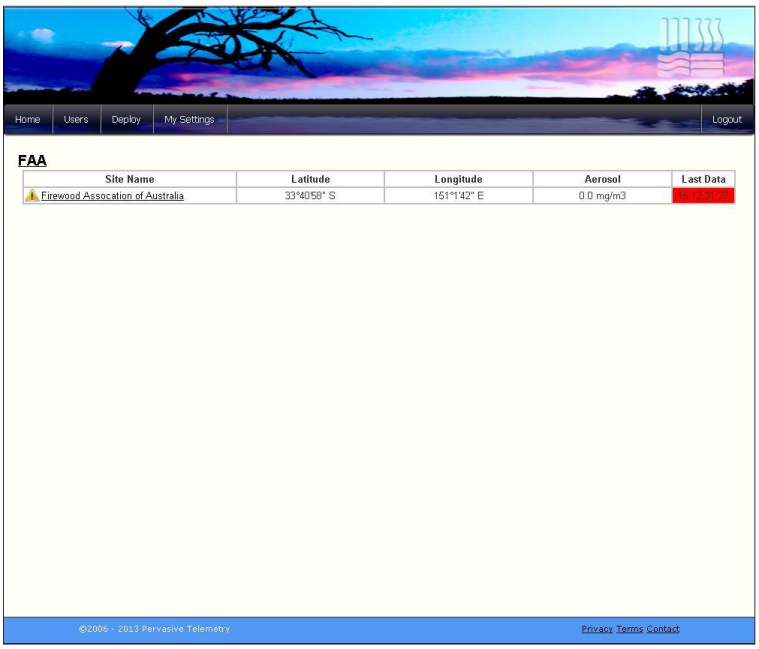
To activate the system, the case is opened, the power cord is plugged into the 'cigarette lighter' 12-volt power outlet and the inlet tube is clipped to the top of the window glass in the passenger door. The front passenger window is left slightly open to accommodate the air inlet tube. All of the equipment is hard wired to the power supply so that a single switch turns everything on or off.

The Samsung Galaxy tablet PC is configured to log in to the user's individual account on the Pervasive Telemetry web site at start up. For this project the FAA set up an account with Pervasive Telemetry and a dedicated Telstra SIM card was purchased for the tablet. The tablet PC can use any activated SIM or be connected to the web using a mobile phone as a wireless hot spot. The tablet PC is mainly included for the purpose of checking that everything is working and that the data is being uploaded correctly by the Agent G2. In practice it also acts as a handy GPS navigation device and can be set up to display the vehicle's track.

When switched on, the system works in the following way: A pump in the Dust Track sucks in air from outside the car at 3 litres per minute through the inlet tube. The incoming air is passed through an in-line filter that removes any particles larger than 2.5 microns in diameter. This is done to avoid measuring larger particles such as road and brake dust, so that the system is mainly detecting smoke (approximately 90% of all wood smoke particles are less than 2.5 microns in size). After this, the air is passed through the auto zero module, which corrects for zero drift in the Dust Trak and then into the Dust Trak particle analyser for accurate measurement of particle concentrations which are displayed as milligrams of particulate per cubic metre of air. Particle concentration readings are sent continuously to the Agent G2 data logger which transmits the readings to the Pervasive Telemetry web site every 5 seconds along with the current GPS co-ordinates. If 3G mobile phone access is temporarily unavailable, the data logger stores the readings and transmits them when a 3G phone connection is next obtained.

Below is screen shot of the Pervasive Telemetry home page.

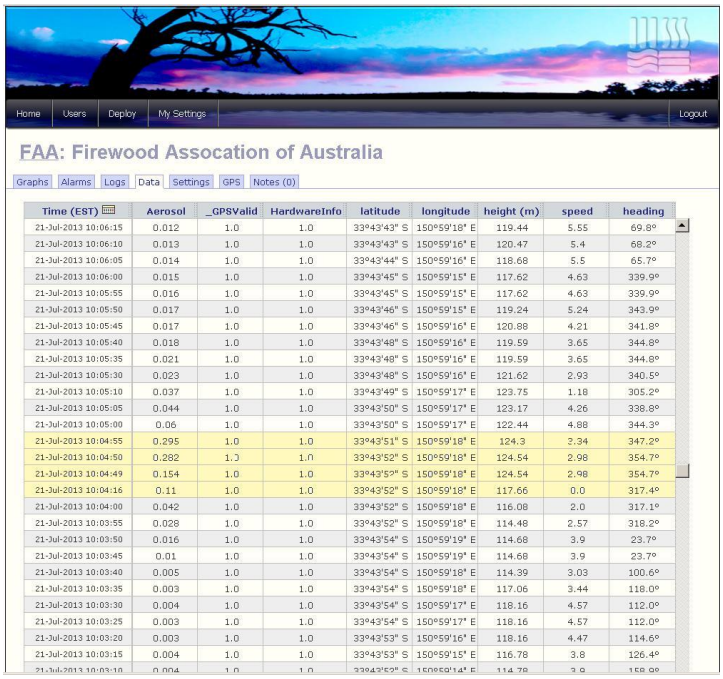
Any Council or interested party can set up an account with Pervasive Telemetry. Pervasive Telemetry charged a $60 per month fee to host the site for this project, but this is only required when the site is being used to upload data. The data on the site remains the property of the client, is secure and confidential requiring a login password to gain access.



When the data is loaded onto the Pervasive Telemetry web site it can be viewed by any web enabled device, such as smart phone, tablet or PC.

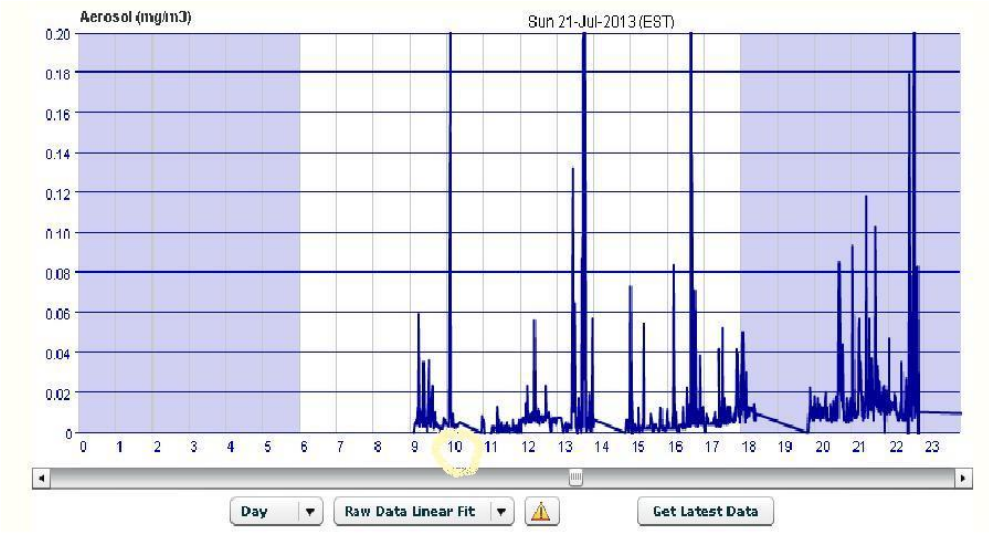
Uploaded data can be viewed in a number of ways.

As a table:

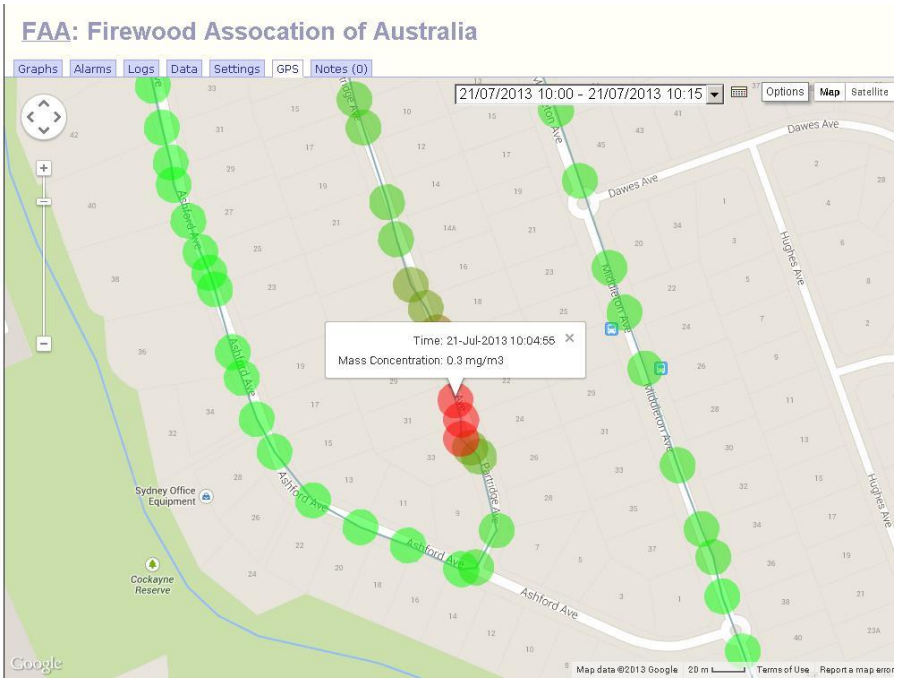


Time (EST)	Aerosol	_GPSValid	HardwareInfo	latitude	longitude	height (m)	speed	heading
21-Jul-2013 10:06:15	0.012	1.0	1.0	33°43'43" S	150°59'18" E	119.44	5.55	69.8°
21-Jul-2013 10:06:10	0.013	1.0	1.0	33°43'43" S	150°59'16" E	120.47	5.4	68.2°
21-Jul-2013 10:06:05	0.014	1.0	1.0	33°43'44" S	150°59'16" E	118.68	5.5	65.7°
21-Jul-2013 10:06:00	0.015	1.0	1.0	33°43'45" S	150°59'15" E	117.62	4.63	339.9°
21-Jul-2013 10:05:55	0.016	1.0	1.0	33°43'45" S	150°59'15" E	117.62	4.63	339.9°
21-Jul-2013 10:05:50	0.017	1.0	1.0	33°43'46" S	150°59'15" E	119.24	5.24	343.9°
21-Jul-2013 10:05:45	0.017	1.0	1.0	33°43'46" S	150°59'16" E	120.88	4.21	341.8°
21-Jul-2013 10:05:40	0.018	1.0	1.0	33°43'48" S	150°59'16" E	119.59	3.65	344.8°
21-Jul-2013 10:05:35	0.021	1.0	1.0	33°43'48" S	150°59'16" E	119.59	3.65	344.8°
21-Jul-2013 10:05:30	0.023	1.0	1.0	33°43'48" S	150°59'16" E	121.62	2.93	340.5°
21-Jul-2013 10:05:10	0.037	1.0	1.0	33°43'49" S	150°59'17" E	123.75	1.18	305.2°
21-Jul-2013 10:05:05	0.044	1.0	1.0	33°43'50" S	150°59'17" E	123.17	4.26	338.8°
21-Jul-2013 10:05:00	0.06	1.0	1.0	33°43'50" S	150°59'17" E	122.44	4.88	344.3°
21-Jul-2013 10:04:55	0.295	1.0	1.0	33°43'51" S	150°59'18" E	124.3	2.34	347.2°
21-Jul-2013 10:04:50	0.282	1.0	1.0	33°43'52" S	150°59'18" E	124.54	2.98	354.7°
21-Jul-2013 10:04:49	0.154	1.0	1.0	33°43'52" S	150°59'18" E	124.54	2.98	354.7°
21-Jul-2013 10:04:16	0.11	1.0	1.0	33°43'52" S	150°59'18" E	117.66	0.0	317.4°
21-Jul-2013 10:04:00	0.042	1.0	1.0	33°43'52" S	150°59'18" E	116.08	2.0	317.1°
21-Jul-2013 10:03:55	0.028	1.0	1.0	33°43'52" S	150°59'18" E	114.48	2.57	318.2°
21-Jul-2013 10:03:50	0.016	1.0	1.0	33°43'54" S	150°59'19" E	114.68	3.9	23.7°
21-Jul-2013 10:03:45	0.01	1.0	1.0	33°43'54" S	150°59'19" E	114.68	3.9	23.7°
21-Jul-2013 10:03:40	0.005	1.0	1.0	33°43'54" S	150°59'18" E	114.39	3.03	100.6°
21-Jul-2013 10:03:35	0.003	1.0	1.0	33°43'54" S	150°59'18" E	117.06	3.44	118.0°
21-Jul-2013 10:03:30	0.004	1.0	1.0	33°43'54" S	150°59'17" E	118.16	4.57	112.0°
21-Jul-2013 10:03:25	0.003	1.0	1.0	33°43'54" S	150°59'17" E	118.16	4.57	112.0°
21-Jul-2013 10:03:20	0.003	1.0	1.0	33°43'53" S	150°59'16" E	118.16	4.47	114.6°
21-Jul-2013 10:03:15	0.004	1.0	1.0	33°43'53" S	150°59'15" E	116.78	3.8	126.4°

As a graph:

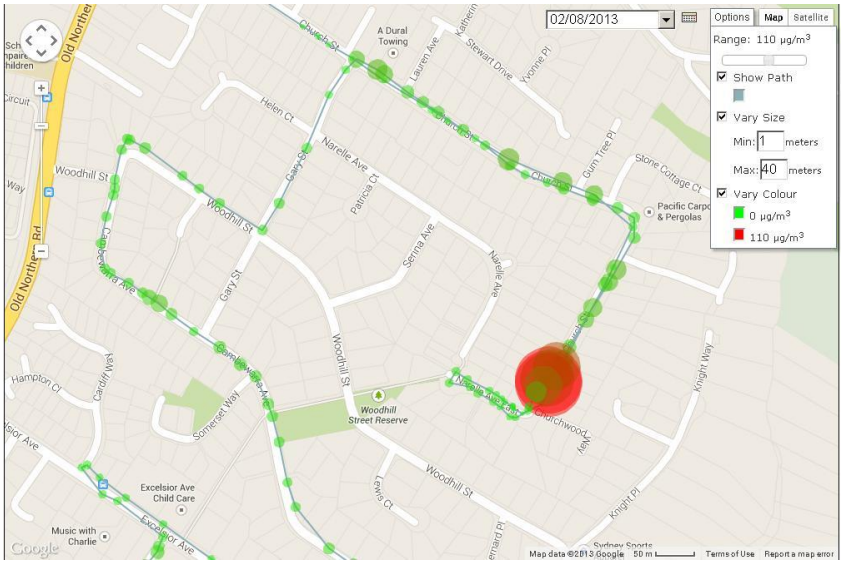


As a Google Map:



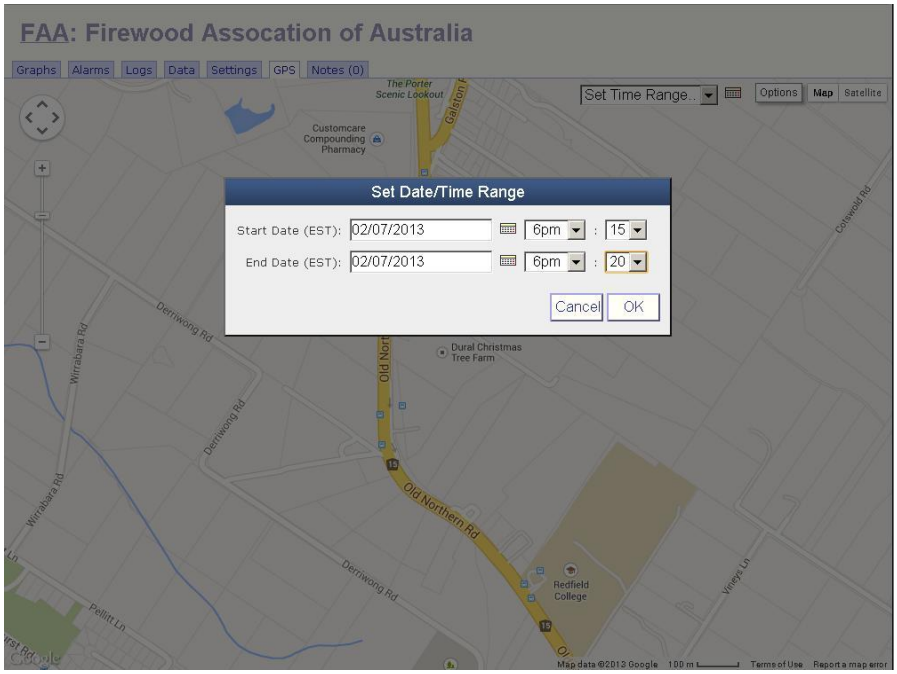
Or projected onto a Satellite “Google Earth” image:

The user can choose the way in which the readings appear on the map or satellite view by selecting various display options.



In the above image the range has been set at 110 µg/m^3, which means that the system will display all readings over 110 µg/m^3 in the upper limit colour, in this case red. Light green is displayed for 0 µg/m^3 with intermediate values displayed in colours graduating from green to red. 'Show path' is selected in this image and the colour of the path is selectable. In this image 'vary size' is selected, which displays 0 µg/m^3 as a dot equivalent to 1 metre in width on the ground and 110 µg/m^3 as a 40-metre-wide dot. The dots are translucent to prevent them from blocking out map detail. When zoomed in it is usually best to set maximum dot size at 2 or 3 metres.

In both GPS Map or Satellite view the data that is displayed can be selected as either the current location, all data for a selected day or data that is within a specified date and time range.



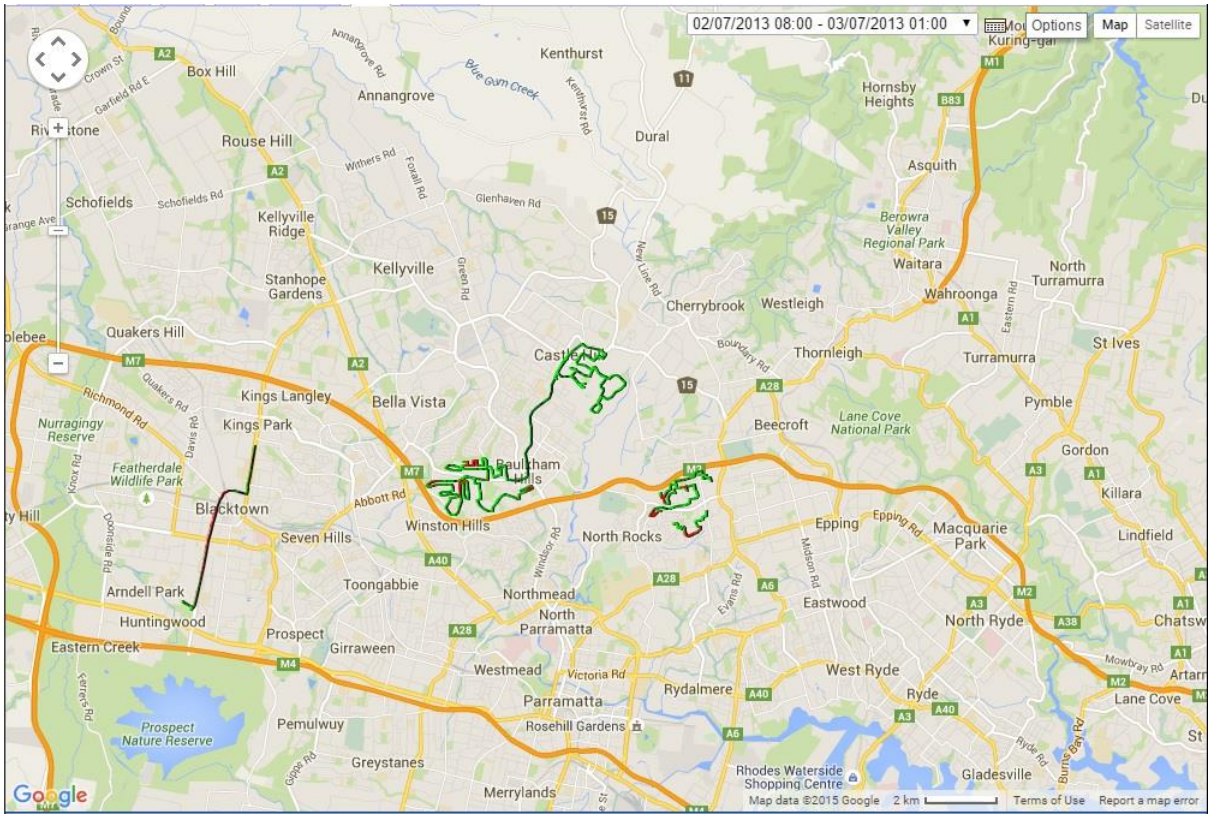
After testing the system in Melbourne, surveying with the *SmokeTrak* device in The Hills Shire commenced on 2 July 2013.

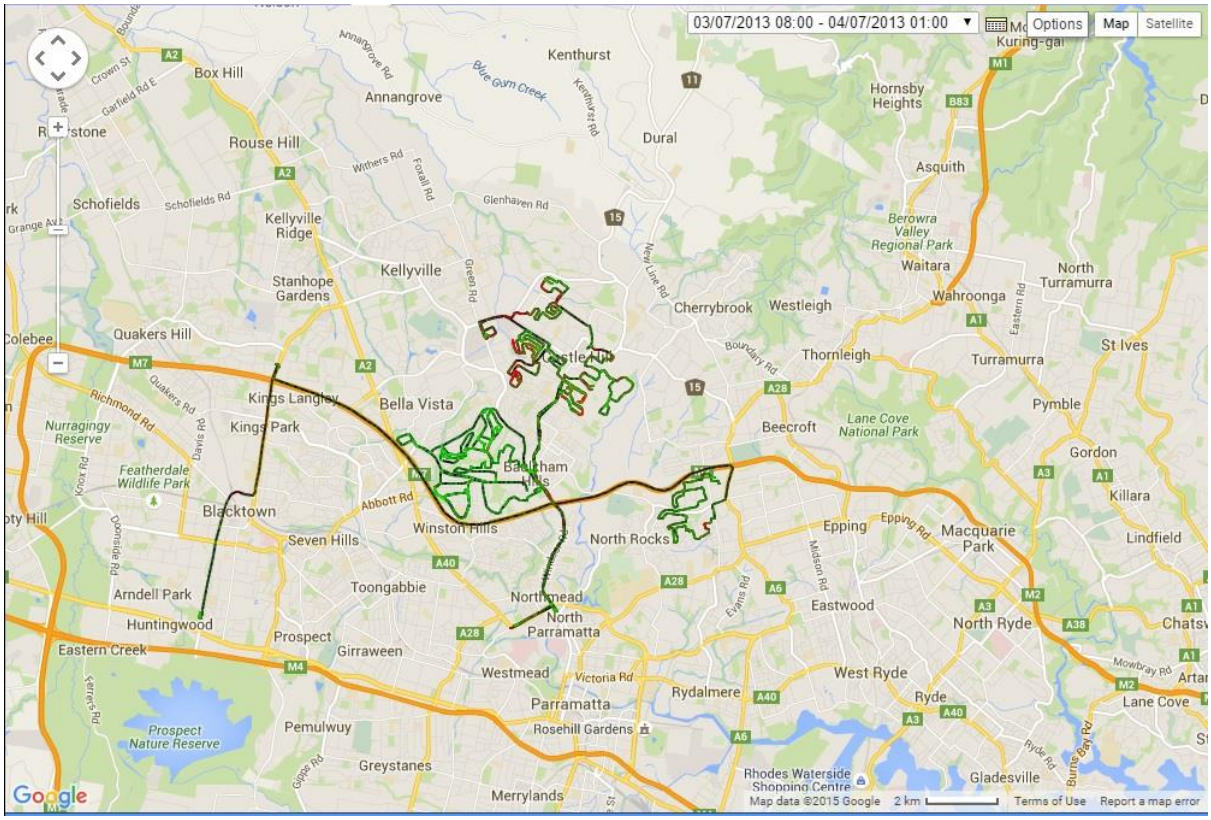
Survey dates and times for July-August 2013 are displayed below to demonstrate the capacity of the system to effectively survey a large area in a reasonably short time frame.

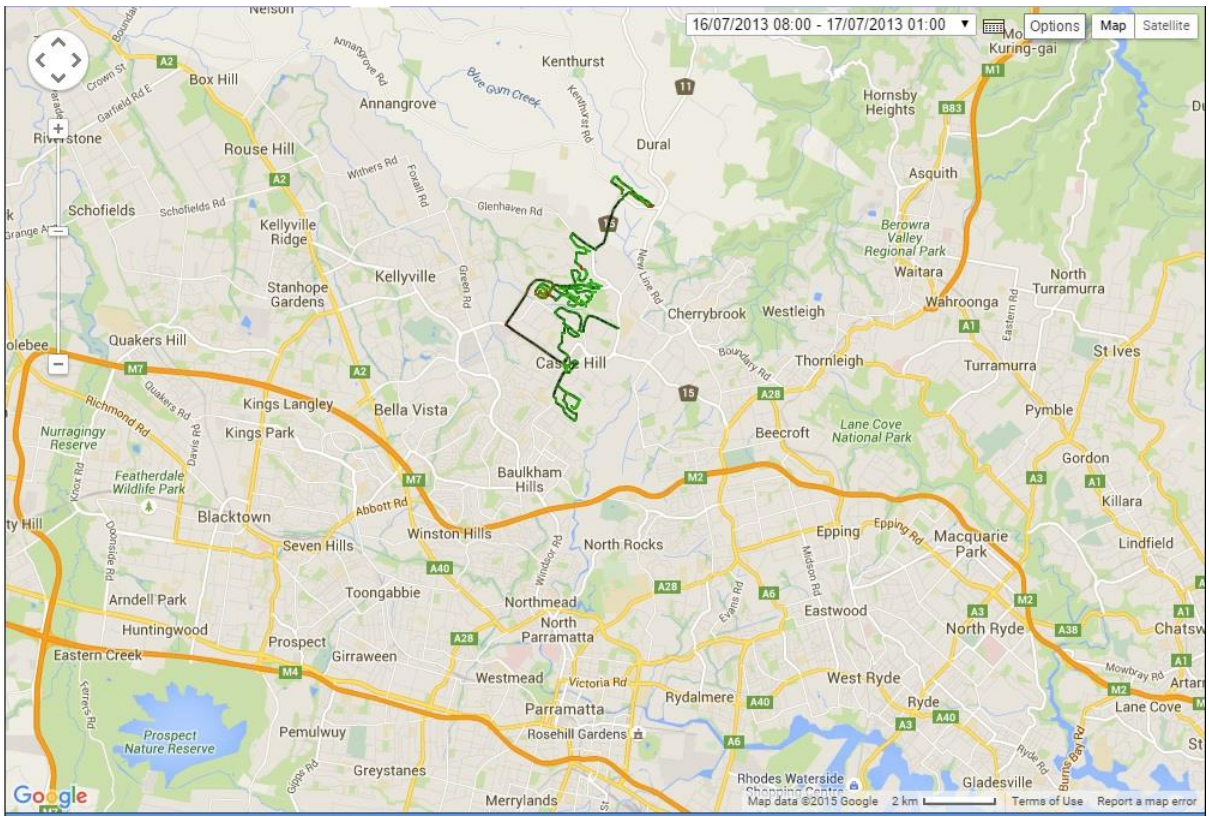
Date	Start	Finish	km of survey route
2/7/2013	6.14 pm	11.13 pm	
3/7/2013	11.12 am	10.28 pm	
			464
16/7/2013	7.54 pm	10.59 pm	
17/7/2013	5.17 pm	10.16 pm	
			276
20/7/2013	7.19 pm	11.24 pm	
21/7/2013	9.05 am	10.50 pm	
22/7/2013	4.30 pm	11.11 pm	
			532
31/7/2013	4.16 pm	11.09 pm	
1/8/2013	9.45 am	11.08 pm	
2/8/2013	10.14 am	11.44 pm	
3/8/2013	10.13 am	10.38 pm	
			749
Total km			**2,021**

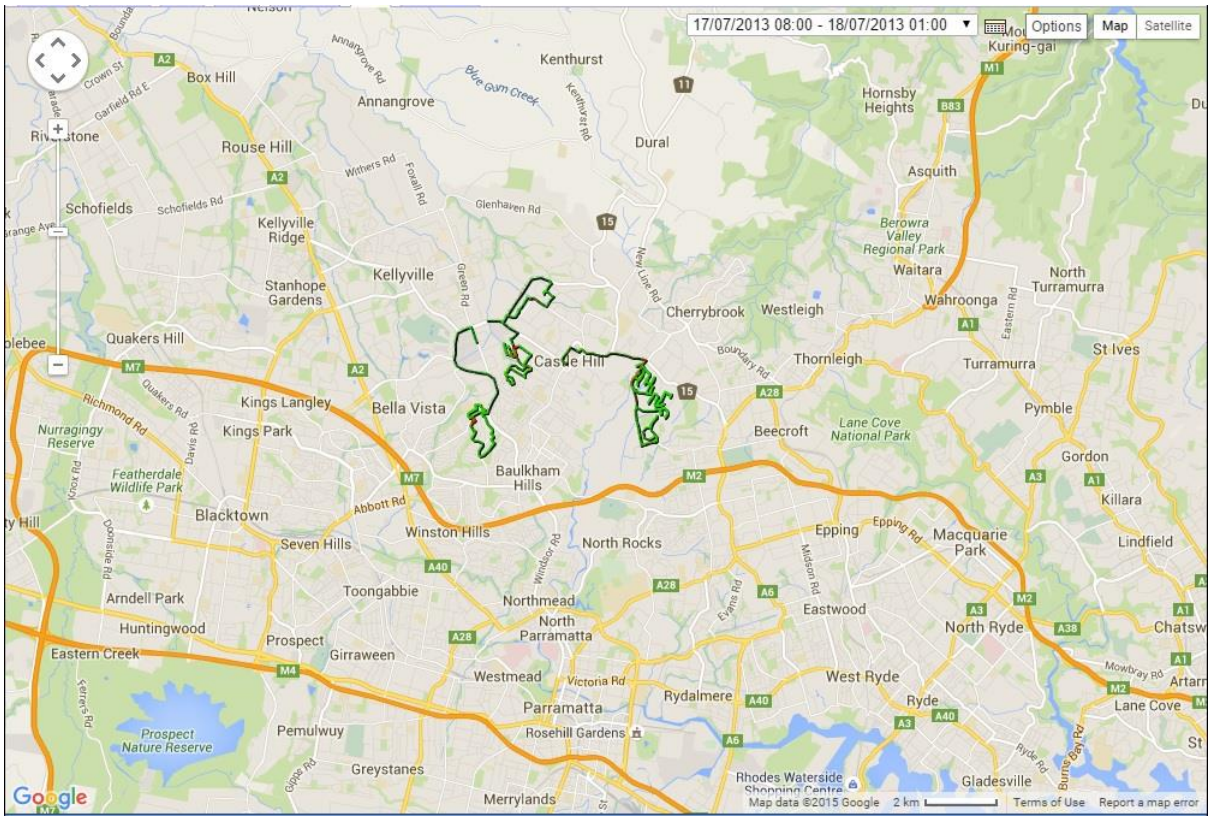
Travel routes

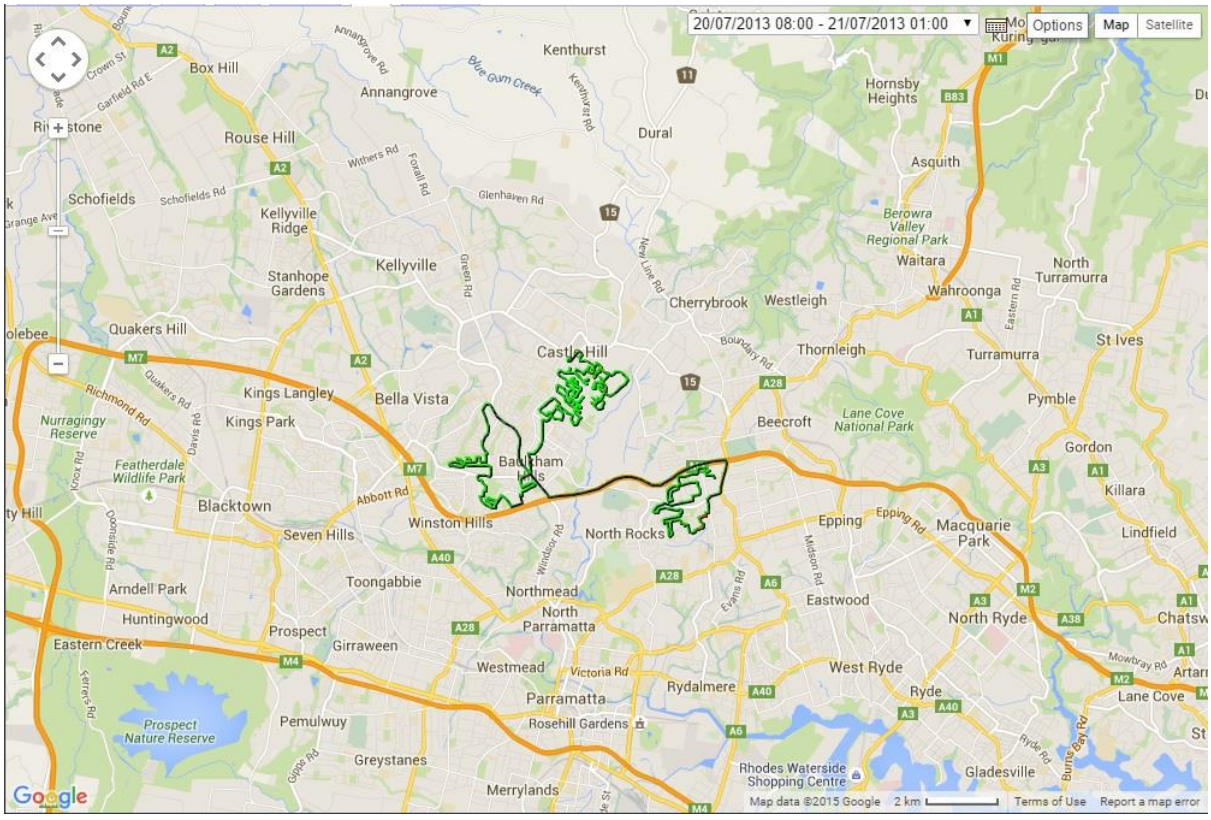
The images below show the travel routes for each day of survey in 2013. Some roads were driven along frequently in the same day and some on repeated occasions in an effort to locate the source of a particular high smoke reading. In some instances, repeat surveys of the same location were carried out to establish a pattern for the smoke emissions from an identified high emitting chimney.

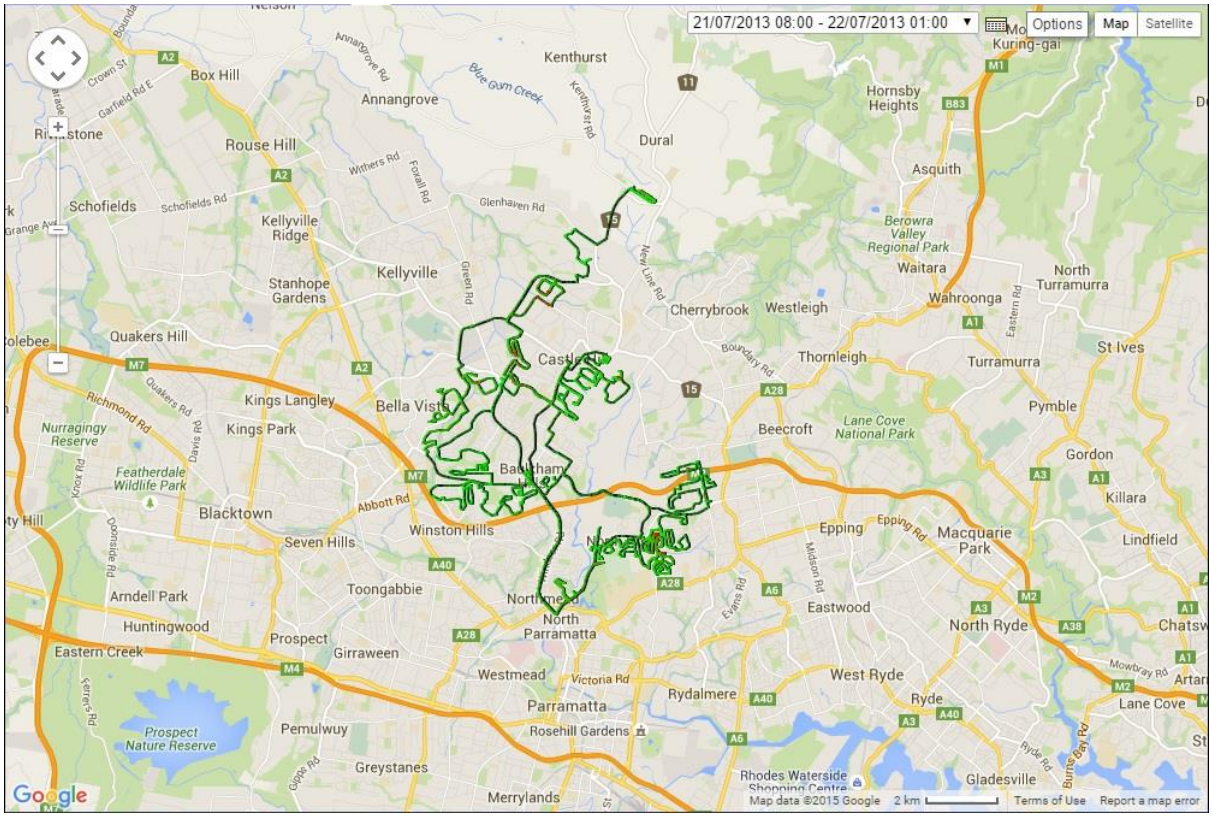


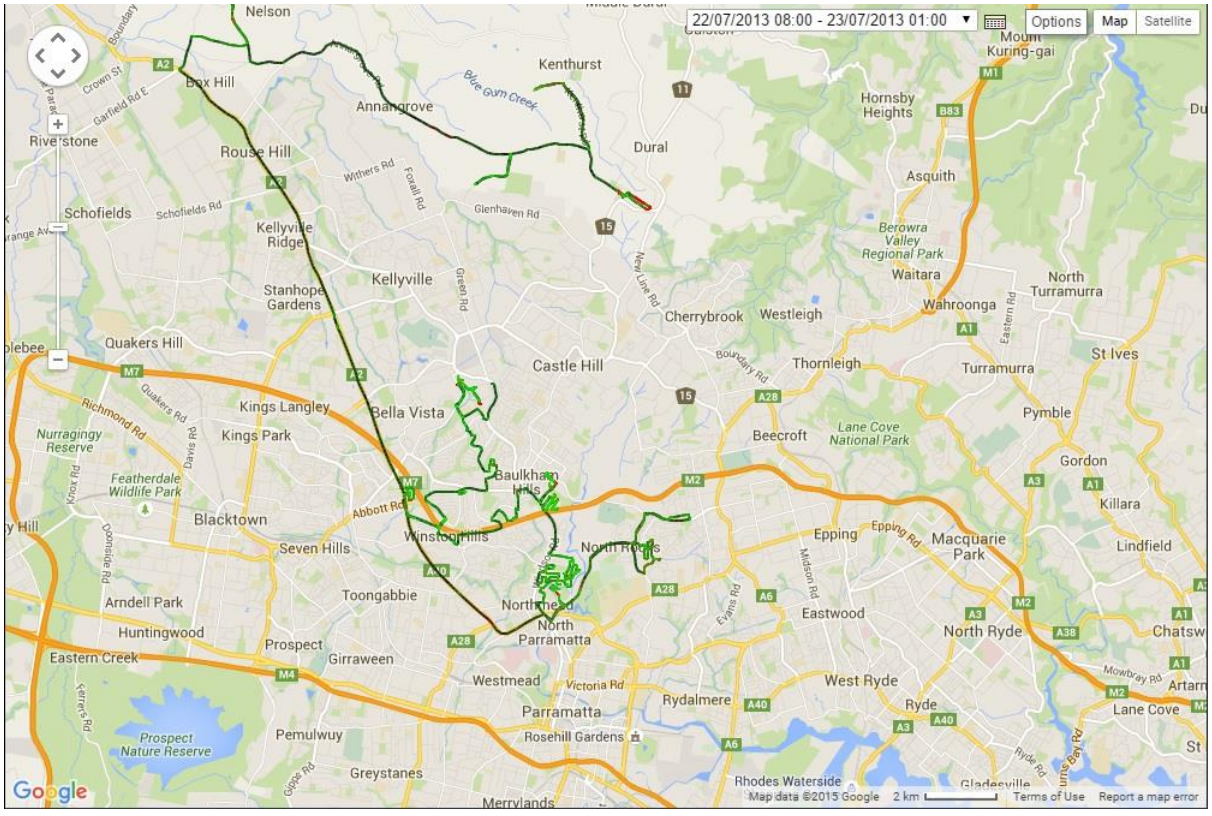

03/07/2013 08:00 - 04/07/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Hornsby Heights
Rouse Hill
Dural
Asquith
Schofields
Kellyville Ridge
Berowra Valley Regional Park
Stanhope Gardens
Kellyville
Waitara
North Turramurra
Cherrybrook
Westleigh
Wahroonga
Quakers Hill
Castle Hill
Thornleigh
St Ives
Turramurra
Kings Langley
Bella Vista
Pymble
Nurragingy Reserve
Kings Park
Beecroft
Lane Cove National Park
Gordon
Featherdale Wildlife Park
Baulkham Hills
Killara
Blacktown
Winston Hills
North Rocks
Epping
Macquarie Park
Lindfield
Seven Hills
Toongabbie
Northmead
Eastwood
Arndell Park
North Parramatta
North Ryde
Huntingwood
Prospect
Girraween
Eastern Creek
Westmead
West Ryde
Victoria Rd
Rydalmere
Ryde
Lane Cove
Parramatta
Prospect Nature Reserve
Pemulwuy
Rosehill Gardens
Greystanes
Rhodes Waterside Shopping Centre
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error

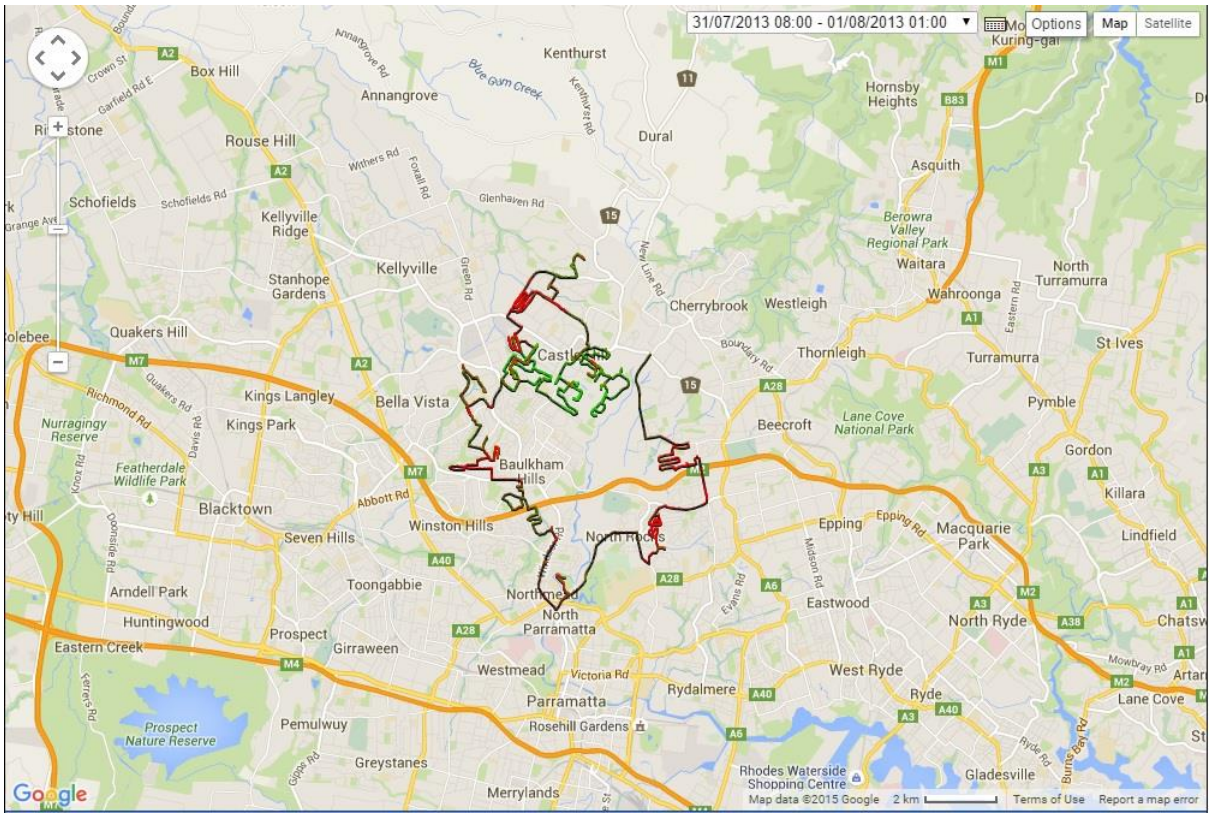

16/07/2013 08:00 - 17/07/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Hornsby Heights
Rouse Hill
Dural
Asquith
Schofields
Kellyville Ridge
Berowra Valley Regional Park
Stanhope Gardens
Kellyville
Waitara
North Turramurra
Cherrybrook
Westleigh
Wahroonga
Quakers Hill
Castle Hill
Thornleigh
St Ives
Turramurra
Kings Langley
Bella Vista
Pymble
Nurragingy Reserve
Kings Park
Beecroft
Lane Cove National Park
Gordon
Featherdale Wildlife Park
Baulkham Hills
Killara
Blacktown
Winston Hills
North Rocks
Epping
Macquarie Park
Lindfield
Seven Hills
Toongabbie
Northmead
Eastwood
Arndell Park
North Parramatta
North Ryde
Huntingwood
Prospect
Girraween
Eastern Creek
Westmead
West Ryde
Victoria Rd
Rydalmere
Ryde
Lane Cove
Parramatta
Prospect Nature Reserve
Pemulwuy
Rosehill Gardens
Greystanes
Rhodes Waterside
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error

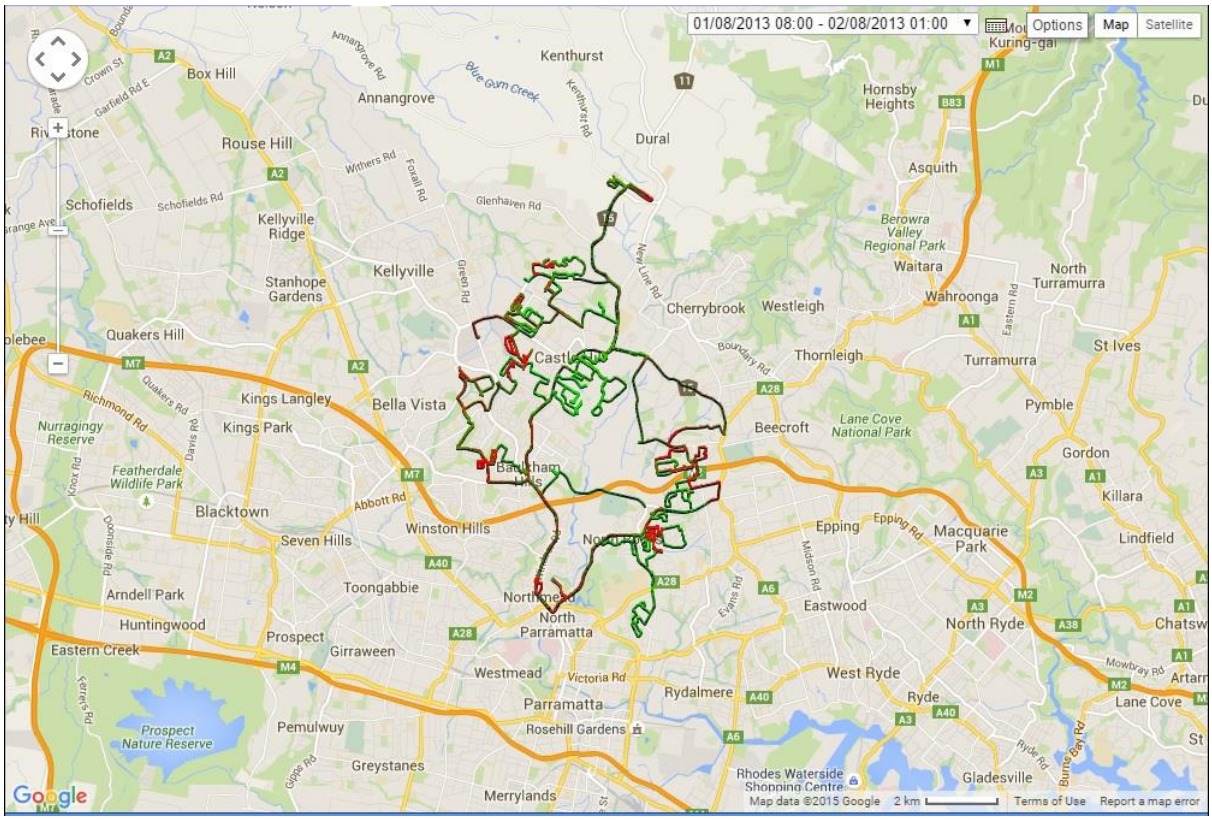

17/07/2013 08:00 - 18/07/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Dural
Hornsby Heights
Asquith
Rouse Hill
Schofields
Kellyville Ridge
Kellyville
Stanhope Gardens
Cherrybrook
Westleigh
Waitara
Wahroonga
North Turramurra
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Kings Park
Beecroft
Pymble
Nurragingy Reserve
Featherdale Wildlife Park
Baulkham Hills
Gordon
Killara
Blacktown
Seven Hills
Winston Hills
North Rocks
Epping
Macquarie Park
Lindfield
Arndell Park
Toongabbie
Northmead
Eastwood
North Ryde
Huntingwood
Prospect
North Parramatta
Eastern Creek
Girraween
Westmead
West Ryde
Rydalmere
Parramatta
Ryde
Lane Cove
Prospect Nature Reserve
Pemulwuy
Rosehill Gardens
Greystanes
Rhodes Waterside Shopping Centre
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error

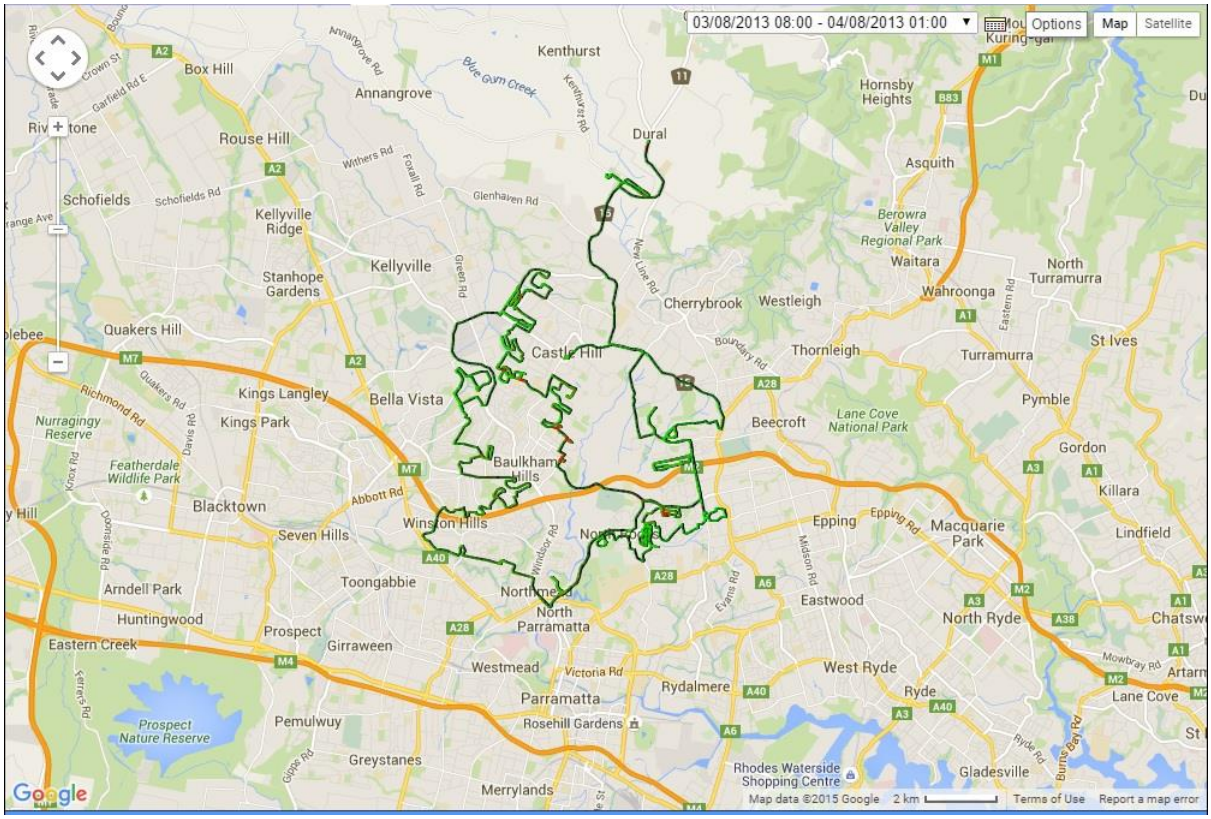

20/07/2013 08:00 - 21/07/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Dural
Hornsby Heights
Asquith
Rouse Hill
Schofields
Kellyville Ridge
Kellyville
Stanhope Gardens
Cherrybrook
Westleigh
Waitara
Wahroonga
North Turramurra
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Kings Park
Beecroft
Pymble
Nurragingy Reserve
Featherdale Wildlife Park
Baulkham Hills
Gordon
Killara
Blacktown
Seven Hills
Winston Hills
North Rocks
Epping
Macquarie Park
Lindfield
Arndell Park
Toongabbie
Northmead
Eastwood
North Ryde
Huntingwood
Prospect
North Parramatta
Eastern Creek
Girraween
Westmead
West Ryde
Rydalmere
Parramatta
Ryde
Lane Cove
Prospect Nature Reserve
Pemulwuy
Rosehill Gardens
Greystanes
Rhodes Waterside Shopping Centre
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error

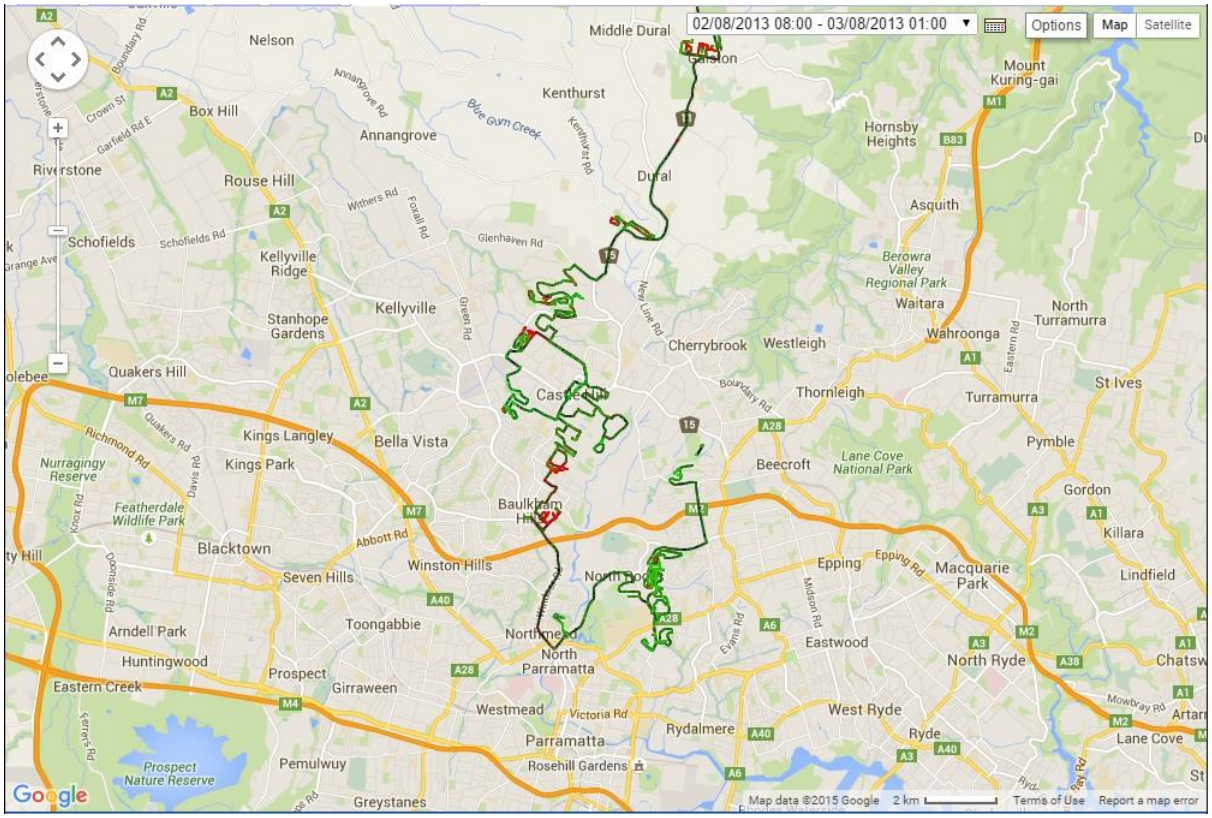

21/07/2013 08:00 - 22/07/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Dural
Hornsby Heights
Asquith
Rouse Hill
Schofields
Kellyville Ridge
Kellyville
Stanhope Gardens
Cherrybrook
Westleigh
Waitara
Wahroonga
North Turramurra
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Kings Park
Beecroft
Pymble
Lane Cove National Park
Nurragingy Reserve
Featherdale Wildlife Park
Baulkham Hills
Gordon
Killara
Blacktown
Abbott Rd
Winston Hills
Seven Hills
Epping
Macquarie Park
Lindfield
Arndell Park
Toongabbie
Northmead
North Parramatta
Eastwood
North Ryde
Huntingwood
Prospect
Girraween
Eastern Creek
Westmead
Victoria Rd
West Ryde
Rydalmere
Parramatta
Ryde
Lane Cove
Prospect Nature Reserve
Pemulwuy
Rosehill Gardens
Greystanes
Rhodes Waterside
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error


22/07/2013 08:00 - 23/07/2013 01:00
Options
Map
Satellite
Nelson
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Dural
Hornsby Heights
Asquith
Rouse Hill
Schofields
Kellyville Ridge
Kellyville
Stanhope Gardens
Cherrybrook
Westleigh
Waitara
Wahroonga
North Turramurra
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Kings Park
Beecroft
Pymble
Lane Cove National Park
Nurragingy Reserve
Featherdale Wildlife Park
Baulkham Hills
Gordon
Killara
Blacktown
Abbott Rd
Winston Hills
Seven Hills
Epping
Macquarie Park
Lindfield
Arndell Park
Toongabbie
Northmead
North Parramatta
Eastwood
North Ryde
Huntingwood
Prospect
Girraween
Eastern Creek
Westmead
Victoria Rd
West Ryde
Rydalmere
Parramatta
Ryde
Lane Cove
Prospect Nature Reserve
Pemulwuy
Rosehill Gardens
Greystanes
Rhodes Waterside
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error


31/07/2013 08:00 - 01/08/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Hornsby Heights
Rouse Hill
Dural
Asquith
Schofields
Kellyville Ridge
Glenhaven Rd
Berowra Valley Regional Park
Stanhope Gardens
Kellyville
Waitara
North Turramurra
Cherrybrook
Westleigh
Wahroonga
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Pymble
Nurragingy Reserve
Kings Park
Beecroft
Lane Cove National Park
Gordon
Baulkham Hills
Featherdale Wildlife Park
Killara
Blacktown
Abbott Rd
Winston Hills
Epping
Macquarie Park
Lindfield
Seven Hills
North Rocks
Toongabbie
Arndell Park
Northmead
Eastwood
North Ryde
Huntingwood
North Parramatta
Prospect
Eastern Creek
Girraween
Westmead
Victoria Rd
West Ryde
Rydalmere
Parramatta
Ryde
Lane Cove
Pemulwuy
Rosehill Gardens
Prospect Nature Reserve
Greystanes
Rhodes Waterside Shopping Centre
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error


01/08/2013 08:00 - 02/08/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Blue Gum Creek
Hornsby Heights
Rouse Hill
Dural
Asquith
Schofields
Kellyville Ridge
Glenhaven Rd
Berowra Valley Regional Park
Stanhope Gardens
Kellyville
Waitara
North Turramurra
Cherrybrook
Westleigh
Wahroonga
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Pymble
Nurragingy Reserve
Kings Park
Beecroft
Lane Cove National Park
Gordon
Baulkham Hills
Featherdale Wildlife Park
Killara
Blacktown
Abbott Rd
Winston Hills
Epping
Macquarie Park
Lindfield
Seven Hills
Toongabbie
Arndell Park
Northmead
Eastwood
North Ryde
Huntingwood
North Parramatta
Prospect
Eastern Creek
Girraween
Westmead
Victoria Rd
West Ryde
Rydalmere
Parramatta
Ryde
Lane Cove
Pemulwuy
Rosehill Gardens
Prospect Nature Reserve
Greystanes
Rhodes Waterside Shopping Centre
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error


03/08/2013 08:00 - 04/08/2013 01:00
Options
Map
Satellite
Kenthurst
Box Hill
Annangrove
Dural
Hornsby Heights
Asquith
Rouse Hill
Schofields
Kellyville Ridge
Kellyville
Stanhope Gardens
Cherrybrook
Westleigh
Waitara
Wahroonga
North Turramurra
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Kings Park
Beecroft
Pymble
Nurragingy Reserve
Baulkham Hills
Gordon
Featherdale Wildlife Park
Blacktown
Winston Hills
Seven Hills
Epping
Macquarie Park
Killara
Lindfield
Arndell Park
Toongabbie
Eastwood
North Ryde
Huntingwood
Prospect
North Parramatta
Eastern Creek
Girraween
Westmead
West Ryde
Rydalmere
Ryde
Lane Cove
Parramatta
Pemulwuy
Rosehill Gardens
Prospect Nature Reserve
Greystanes
Rhodes Waterside Shopping Centre
Gladesville
Merrylands
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error


02/08/2013 08:00 - 03/08/2013 01:00
Options
Map
Satellite
Nelson
Middle Dural
Mount Kuring-gai
Kenthurst
Box Hill
Annangrove
Dural
Hornsby Heights
Asquith
Riverstone
Rouse Hill
Schofields
Kellyville Ridge
Kellyville
Stanhope Gardens
Cherrybrook
Westleigh
Waitara
Wahroonga
North Turramurra
Quakers Hill
Castle Hill
Thornleigh
Turramurra
St Ives
Kings Langley
Bella Vista
Kings Park
Beecroft
Pymble
Nurragingy Reserve
Baulkham Hills
Gordon
Featherdale Wildlife Park
Blacktown
Winston Hills
Seven Hills
Epping
Macquarie Park
Killara
Lindfield
Arndell Park
Toongabbie
Eastwood
North Ryde
Huntingwood
Prospect
North Parramatta
Eastern Creek
Girraween
Westmead
West Ryde
Rydalmere
Ryde
Lane Cove
Parramatta
Pemulwuy
Rosehill Gardens
Prospect Nature Reserve
Greystanes
Google
Map data ©2015 Google
2 km
Terms of Use
Report a map error

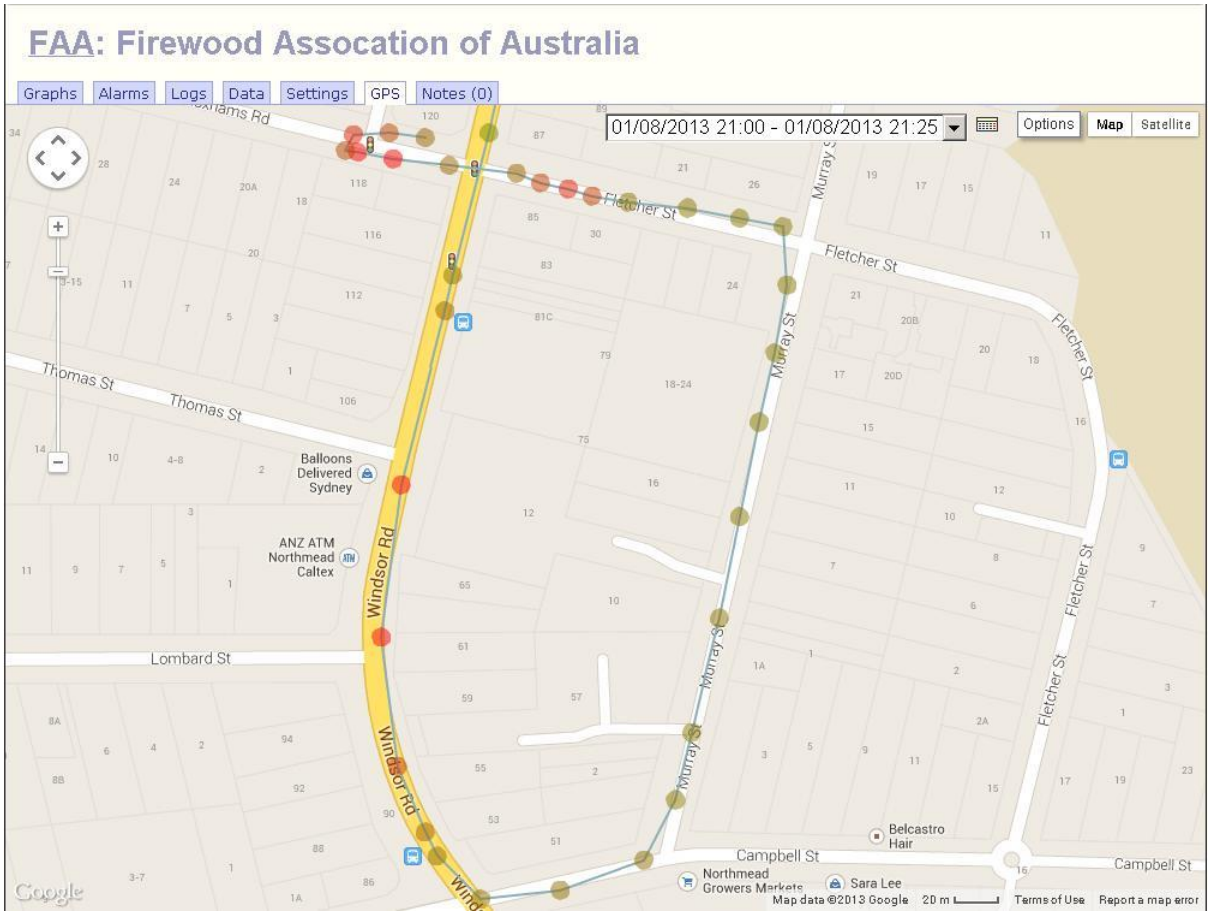
Locating individual plumes

Even though the *"SmokeTrack"* system can locate the source of high smoke concentrations with reasonable accuracy, it is usually necessary to confirm the high emitting flue by visual observation. For example, two adjacent houses can have chimneys that are separated by just a couple of metres. It is also possible that two adjacent households could be emitting excessive smoke at the same time. At night, even when there is good moonlight, wood smoke simply cannot be seen without the aid of artificial light. Sometimes street lights are sufficient for this, but it was found that a powerful torch with a very narrow beam provided the best means of identification. High power, narrow beam torches are readily available from hunting and fishing equipment stores. Note that the use of a torch for this purpose needs to be kept to a minimum, as residents may well become concerned about people shining a torch at their roof in the middle of the night.

Adjusting for time lag in the system

Due the length of time it takes for air to travel from the tube inlet to the Dust Trak, even at 3 litres per minute there is an unavoidable time lag between the intake of smoke and its detection. Depending on the speed of travel, this time lag means that smoke readings are initially displayed on the telemetry some distance from their actual source. In practice, it was reasonably simple to determine the location of the highest reading by turning the car around, or reversing at a slow speed if practicable, to locate the highest reading for the particular source.

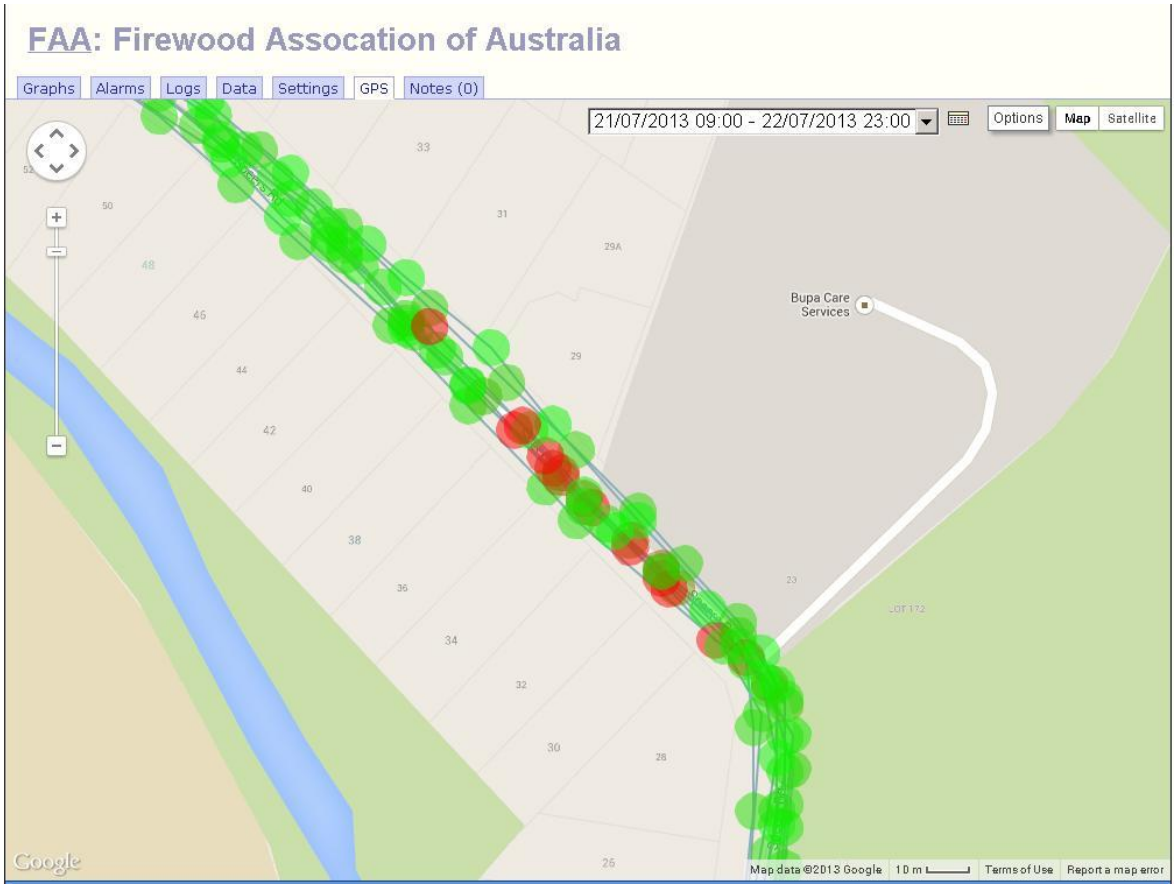
The image below shows how this works in practice. While driving at 60 kph in heavy traffic heading south along Windsor Rd., a high reading alarm sounded at about Thomas St. Obviously the source was further back along Windsor Rd. therefore to locate it, a left turn was made at Campbell St., and the car was driven around the block to the intersection at Fletcher St and Windsor Rd. While stationary at the traffic lights, heavy smoke was observed coming from a house near the corner of Moxhams Rd and Windsor Rd. This observation was made possible by the strong street lighting along Windsor Rd.



On most occasions smoke was detected at low speed in suburban streets, which allows the system to more accurately locate the source. At night, even when this occurred it was preferable to drive back past the source to confirm its exact location by torch.

Repeated observation

Occasionally high smoke readings were obtained but the household that was emitting the smoke was not able to be confirmed. When this occurred, the location was noted and the area was surveyed repeatedly in both daylight and at night in an attempt to locate the source. In most instances the high emitting household was found eventually.



The unusually warm weather in Sydney at the time of testing of the system in 2013 meant that many fires were only lit infrequently, making positive identification haphazard. Fortunately, it appears that many of the highest smoke emitters operate their fires for longer periods than most wood burning households, some even burning their fires on quite warm days, which assisted in their visual confirmation.

Visualising smoke plume dispersion

The direction and spread of smoke plumes from forest fires and other high emission point sources has been studied for a long time by environment protection authorities. Atmospheric dispersion modelling is the mathematical simulation of how air pollutants disperse in the atmosphere. It is performed with computer programs that solve the mathematical equations and algorithms which simulate the pollutant dispersion. These dispersion models are used to estimate or to predict the downwind concentration of air pollutants or toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases.

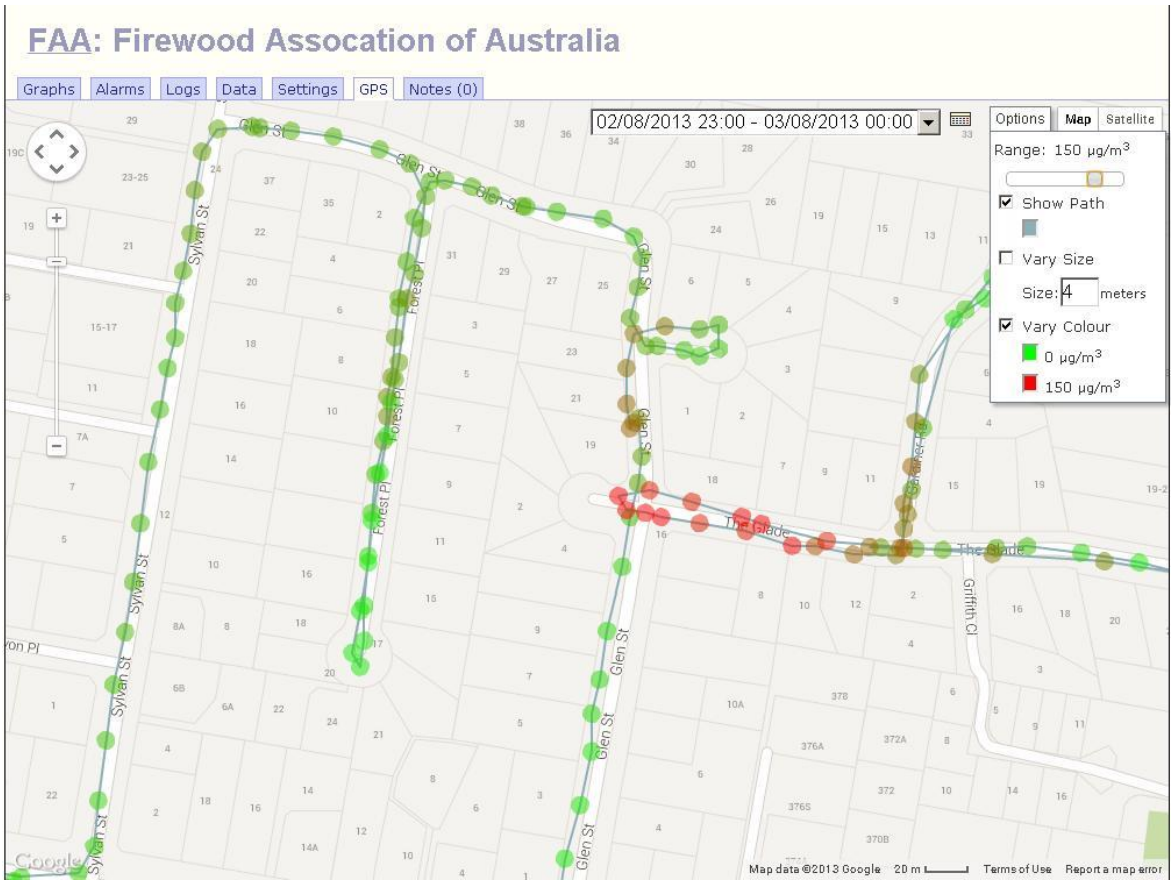
The amount of smoke emitted by a single domestic wood heater is generally too small and irregular for dispersion modelling to be applied meaningfully. One of the valuable features of the *"SmokeTrak"* system is that it can be used to produce a visual representation of the dispersion pattern of smoke from a single high emitting domestic chimney.

The way this works is shown in the images below.

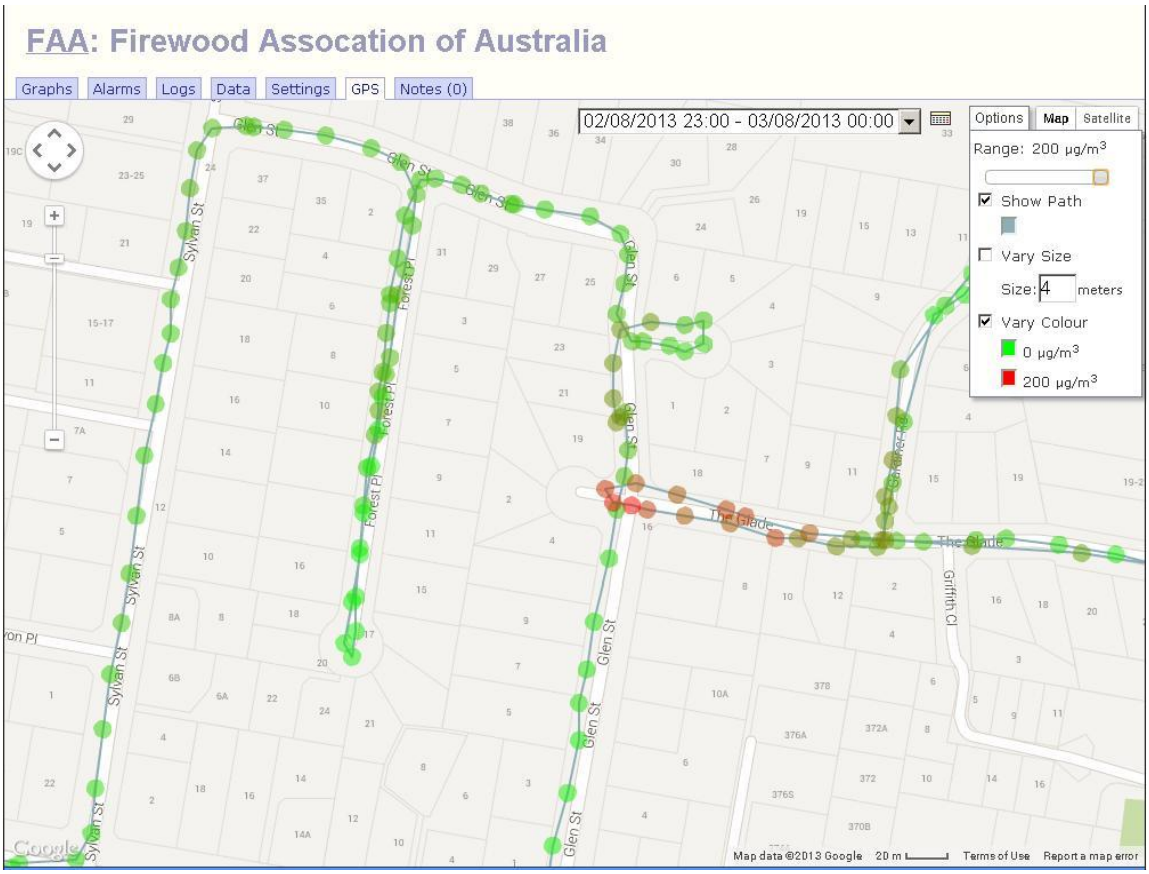
The selected area is in the village of Galston, a part of The Hornsby Shire at the time of this project and therefore outside the study area. The Google Earth image below shows the topography of the village. The detected smoke was coming from a house located near the head of a shallow valley that slopes gently to the North West.

The images below show how the "*SmokeTrak*" system can be used to show the smoke dispersion pattern from this single source.

In the first image the single high emitting source is shown by the red dots, in this map the red dots represent a smoke concentration of 200 μg/m^3 per cubic metre or greater. Although the wind was quite calm the smoke was drifting slowly down the The Glade to the West



In the next image, the range has been reduced so that the red dots now represent 150 μg/m^3 or more. This shows that the highest concentration is still straight down the street but displays the spread of the smoke, mainly to the north as shown by the brown dots.


FAA: Firewood Assocation of Australia
Graphs
Alarms
Logs
Data
Settings
GPS
Notes (0)
02/08/2013 23:00 - 03/08/2013 00:00
Options
Map
Satellite
Range: 200 µg/m3
Show Path
Vary Size
Size: 4 meters
Vary Colour
0 µg/m3
200 µg/m3
Sylvan St
Glen St
Forest Pl
The Glade
Griffith Cl
Map data ©2013 Google
20 m
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By further reducing the range to 100 µg/m^3 the spread and dilution of the smoke starts to become obvious.

At 75 µg/m^3 it is clear that the smoke is spreading over a large area and slowly drifting down the valley.

At 50 µg/m^3, the effect of the smoke from this single source can be clearly seen. It is worth noting that the top end of the Forest Place cul-de-sac, which is on a slight rise, was completely unaffected. It appears as though the smoke was behaving much like a liquid in this instance, flowing down the valley close to ground level. The spread of smoke that can be seen going up Sylvan Street was most likely dragged along by cars. Also of note is that there was some uphill drift, although this may be due to the intermittent and fickle nature of the very light wind conditions at the time of survey.

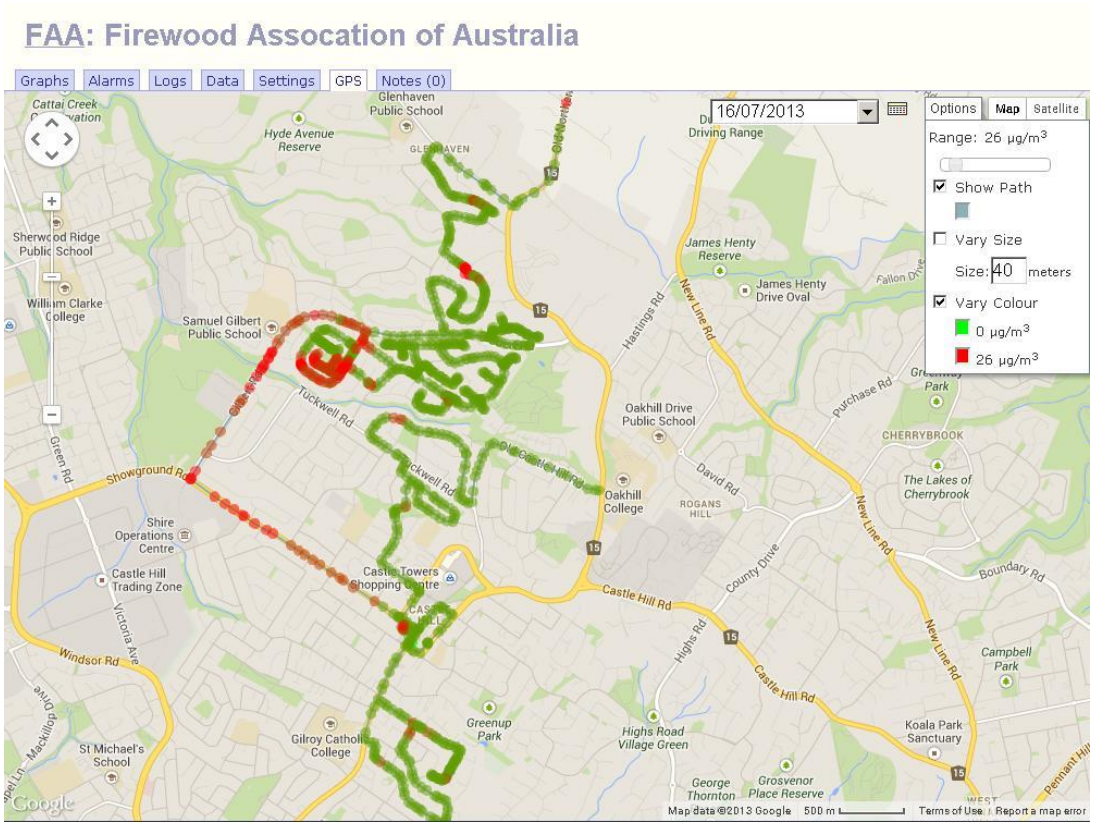
Therefore, by varying the range settings for particulate concentration on the Pervasive Telemetry GPS mapping function, it is possible to produce a visual representation of smoke concentration and dispersion using the *Smoke Trak* system, provided there are roads in the direction of the smoke drift.

What this process clearly demonstrates is that, under the right climatic and topographic conditions, smoke from a single badly operated wood heater can spread over a wide area, creating poor air quality for nearby residents. By simply correcting this one householder's heater operating practice, most the village of Galston would have been relieved from the odour and health impact of the smoke created by a single wood heater.

Ambient air quality

Under the reporting requirements of the National Environment Protection (Ambient Air Quality) Measure[24] a 24-hour exposure limit for fine particles of 2.5 micron or less has been set at 25μg/m^3. By adjusting the range maximum in the GPS map function of the Pervasive Telemetry site it is possible to get a visual representation of ambient air quality. As can be seen in the example below, air quality is mostly very good (green dots) but there are some hot spots created by excessively smoking flues. Of interest is the high level of particulates along heavily trafficked roads such as Showground Rd. Residents adjacent to such roads will almost certainly be receiving more than the maximum permitted 24-hour average exposure of $PM_{2.5}$. Also worth noting is the occasional high spot reading from other sources. The high reading near the corner of Showground Road and Old Northern Road at Castle Hill was actually taken in the McDonalds car park, and was presumably smoke from the restaurant kitchen. Some other high spot readings were caused by exhaust smoke from diesel engine vehicles, especially buses and small utilities.

[24] Standing Council on Environment and Water (2015). National Environment Protection (Ambient Air Quality) Measure. From www.scew.gov.au/nepms/ambient-air-quality.



Comment on *SmokeTrack* system testing

Testing of the *SmokeTrak* system in 2013 confirmed its effectiveness for locating high wood smoke emitting households, and also in identifying areas that experience poor winter air quality as a result of excessive domestic wood smoke. The linkage with Pervasive Telemetry minimises the need for additional data entry and allows system users to access and analyse readings at their convenience. The system has therefore overcome one of the major difficulties identified by the Launceston study; the time and cost of conducting smoke surveys and recording and analysing survey results.

Phase 2 Project Activities (2104)

Targeted behaviour change intervention

Selecting target households

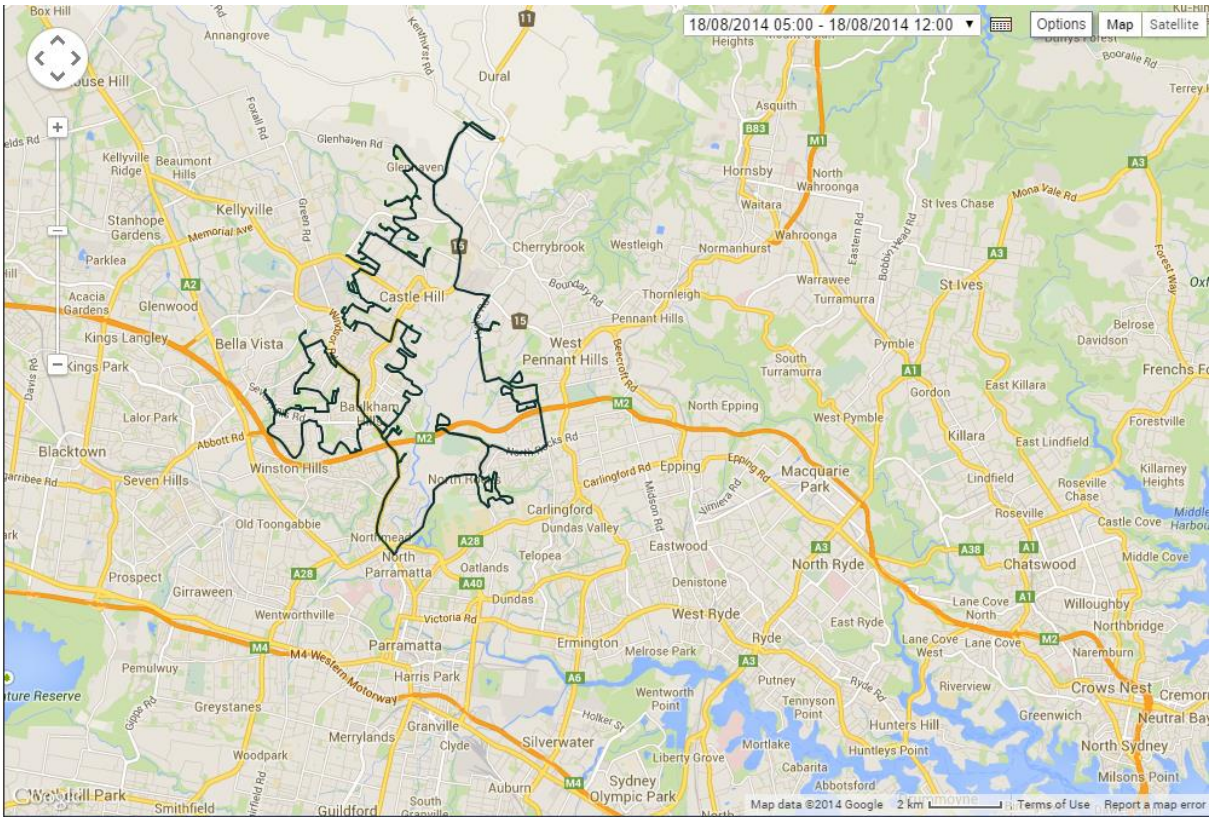
Using the *SmokeTrak* system, smoke surveying for Phase 2 of the project commenced on the 11th of June 2014. The aim of the smoke surveys was to identify and confirm the households that were to be included in the field trial of a targeted intervention program. Unfortunately, the unseasonably warm weather in Sydney throughout the month of June (2014) meant that very few people were using their wood fires which limited the number of houses that could be confirmed as regular high smoke emitters.

Surveying in early July was, however more successful with a good number of high emitting households being identified. Many of the houses that were initially identified as high smoke emitters during the 2013 testing of the *SmokeTrak* system were found to be regularly emitting excessive smoke again in 2014. Several new households were also identified as potential regular high emitters. Surveying from the 14th July to the 2nd August was used to confirm the high emitters and some further high emitting households were identified.

From the thousands of households that were surveyed, a total of 136 households were observed emitting high levels of smoke on more than one occasion in either 2013 or 2014. From these "high emitters" 60 households were selected along a travel route that would allow all households to be observed within a time frame of 4-5 hours. This time frame was chosen to permit every household to be observed up to three times per day i.e. morning, daytime and evening. Changing the starting location and/or direction of travel along the route provided variation in the times at which observations of the targeted households were made.

The travel route was also selected to cover as much of the shire's demographic profile as was practicable, but excluded the more remote rural areas of the shire.

Below is a map from the *SmokeTrak* system showing the selected survey travel route for the 60 households in the study:


18/08/2014 05:00 - 18/08/2014 12:00
Options
Map
Satellite
Castle Hill
West Pennant Hills
Baulkham Hills
Winston Hills
Seven Hills
Blacktown
Bella Vista
Kellyville
Glenwood
Cherrybrook
Pennant Hills
Carlingford
Epping
Macquarie Park
North Ryde
Chatswood
Parramatta
Ermington
Silverwater
Sydney Olympic Park
Auburn
Hornsby
St Ives
Pymble
Gordon
Killara
Lindfield
Roseville
Willoughby
Crows Nest
Greenwich
North Sydney
Milsons Point
Hunters Hill
Ryde
West Ryde
Eastwood
Dundas
Telopea
Oatlands
Harris Park
Merrylands
Granville
Guildford
Smithfield
Wentworthville
Prospect
Girraween
Pemulwuy
Greystanes
Woodpark
Clyde
Liberty Grove
Mortlake
Cabarita
Abbotsford
Huntleys Point
Wentworth Point
Tennyson Point
Putney
Melrose Park
Denistone
Dundas Valley
Carlingford
Old Toongabbie
Northmead
North Parramatta
Lane Cove
Lane Cove West
Lane Cove North
Naremburn
Northbridge
Neutral Bay
Cremorne
Riverview
Map data ©2014 Google
2 km
Terms of Use
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The following table shows the streets and suburbs of the targeted houses along the travel route. Individual house numbers are not shown for privacy reasons.

Street	**Suburb**	**Street**	**Suburb**
Baulkham Hills Rd	Baulkham Hills	Nanette Pl	Castle Hill
Candowie Cres	Baulkham Hills	Parsonage Rd	Castle Hill
Cook St	Baulkham Hills	Parsonage Rd	Castle Hill
Cook St	Baulkham Hills	Partridge Ave	Castle Hill
Glanmire Rd	Baulkham Hills	Partridge Ave	Castle Hill
James St	Baulkham Hills	Portsea Pl	Castle Hill
Karen Ct	Baulkham Hills	Southleigh Ave	Castle Hill
Leong Pl	Baulkham Hills	Tuckwell Rd	Castle Hill
Paul Ct	Baulkham Hills	White Cedar Dr	Castle Hill
Raynor Pl	Baulkham Hills	Woodchester Cl	Castle Hill
Sanders Rd	Baulkham Hills	Jaffa Rd	Dural
Seven Hills Rd	Baulkham Hills	Jaffa Rd	Dural
St Michaels Pl	Baulkham Hills	Jaffa Rd	Dural
Ferndale Ave	Carlingford	Jaffa Rd	Dural
Oaks Rd	Carlingford	Kenthurst Rd	Dural
Anneliese Pl	Castle Hill	Old North Rd	Dural
Arlington Ave	Castle Hill	Valencia St	Dural
Ashford Ave	Castle Hill	Valencia St	Dural
Church St	Castle Hill	Sandhurst Cres	Glenhaven
Church St	Castle Hill	Highclere Cres	North Rocks
Dresden Ave	Castle Hill	Northam Dr	North Rocks
Excelsior Rd	Castle Hill	Northam Dr	North Rocks
Excelsior Rd	Castle Hill	Northam Dr	North Rocks
George Mobbs Dr	Castle Hill	Northam Dr	North Rocks
George Mobbs Dr	Castle Hill	Sandler Ave	North Rocks
Kathleen Ave	Castle Hill	Statham Ave	North Rocks
Kathleen Ave	Castle Hill	Windsor Rd	Northmead
McIntire Pl	Castle Hill	Bellbird Dr	West Pennant Hills
Middleton Ave	Castle Hill	Betts Pl	West Pennant Hills
Nanette Pl	Castle Hill	Westmore Dr	West Pennant Hills

Allocating an intervention strategy

The 60 selected, high emitting households were randomly allocated into one of two groups using a random number generator. Forty households were allocated to receive an offer of a free flue clean and 20 were allocated into a Control group. From the 40 households that were sent an offer of a free flue clean, 20 contacted the listed flue cleaning companies to accept the offer. Ten of these households were then randomly allocated into Condition 1 and ten into Condition 2 as detailed below. The 20 households that were sent the offer letter but did not contact either of the listed wood heater service businesses before the cut-off date of the 29th August 2014 were allocated into Condition 3.

Condition 1	Enhanced Face-to-Face intervention - provision of free wood heater service and flue clean plus expert advice and instruction on wood heater maintenance and operation as well as an assessment of wood procurement and storage practices.
Condition 2	Face-to-Face intervention - provision of free wood heater service and flue clean.
Condition 3	Sent a letter offering a free flue clean but did not accept the offer.
Control	No contact made with the household;

Recruiting wood heater service professionals.

On the 2nd of July 2014, The Hills Shire Council sent the following invitation to wood heater maintenance and/or chimney sweeping businesses that are either listed in Sensis directories or on the internet as offering their services to households within The Hills Shire.

THE HILLS SHIRE COUNCIL
3 Columbia Court, Baulkham Hills NSW 2153
PO Box 7064, Baulkham Hills BC NSW 2153
Telephone +61 2 9843 0555
Facsimilie +61 2 9843 0409
DX 9966 Norwest
Email council@thehills.nsw.gov.au
www.thehills.nsw.gov.au
ABN No. 25 034 494 656

02 July 2014

Dear Sir / Madam

Information Evening on Reducing Wood Smoke from Domestic Wood Heaters

---

The Firewood Association of Australia (FAA) and its members have been actively promoting the minimisation of smoke from wood fuelled heaters and considering how best to tackle the local nuisance that a smoky heater can cause. The Firewood Association has been a partner with the University of New England-based research team led by Professor Don Hine examining the issue of pollution from wood heaters by changing people's behaviour in terms of wood heater operation and purchase/storage of firewood.

The FAA is seeking to undertake a pilot project with The Hills Shire Council which will include the identification of high smoke producing households, making contact with the owners and offering some solutions. One of the solutions we want to offer is a clean of their heater and flue. We are looking for people or businesses interested in partnering with the FAA and Council to be on a list to provide this service to the home owner – the cost will be covered by the FAA as part of the program. It would be expected that some of the homes would simply receive a flue clean and system check and some would also receive some additional education information about wood heater operation and firewood management practices.

An information and discussion evening is proposed for 5:30pm on Monday 14th July 2014 at The Hills Shire Council Administration building at 3 Columbia Court Baulkham Hills (Norwest).

It is expected to only take an hour to an hour and a half of your time and light refreshments will be provided. Advice of your attendance for catering would be appreciated. Please rsvp to me on 9843 0555 during normal business hours or email, cbourke@thehills.nsw.gov.au, by Wednesday 9th July 2014.

Yours faithfully

Craig Bourke
ENVIRONMENTAL HEALTH COORDINATOR

Even though a good number of the recipients of this letter contacted Council to say that they would be coming to the event, on the evening of 14 July only two flue cleaning companies attended. These were The Flue Doctor and Sydney Heaters and Pizza Ovens. Both of these companies agreed to participate in the program.

During the evening Alan McGreevy from the FAA and Dr Navjot Bhullar from the UNE delivered presentations on the Project. Mr McGreevy explained why it was essential for the long term future of the firewood industry to find a practical and effective way for councils to deal with domestic wood smoke complaints. The main objectives of the FAA Smoke Reduction Project were outlined and the outcomes from the 2013 phase of the project were presented, including the use of the *SmokeTrak* system. Dr Bhullar explained some of the principles of cognitive behaviour change and outlined the findings from the work that the UNE team have been doing on the domestic wood smoke issue in Armidale. Dr Bhullar also set out the essential design requirements for conducting a field experiment such as this project.

Conducting the interventions

The 40 households that were randomly allocated to receive a targeted intervention were sent a personalised letter from Council offering a free flue clean. A 'pro-forma' copy of the letter is shown on the following page.

THE HILLS SHIRE COUNCIL
3 Columbia Court, Baulkham Hills NSW 2153
PO Box 7064, Baulkham Hills BC NSW 2153
Telephone +61 2 9843 0555
Facsimilie +61 2 9843 0409
Email council@thehills.nsw.gov.au
www.thehills.nsw.gov.au
DX 9966 Norwest
ABN No. 25 034 494 656

30 July 2014

Dear Mr & Mrs

Free Flue Clean Offer

Flue Clean Ref: A14725-2

This winter the Firewood Association of Australia in collaboration with The Hills Shire Council is conducting a trial program aimed at improving the performance of wood heaters and improving wood fire safety in the home. Under this program we are offering a limited number of households in The Hills Shire a free wood heater/fireplace safety check and flue/chimney clean.

Excessive smoke emissions can sometimes be an indicator that there is something wrong with your heater/fireplace or its operation. You have been chosen to receive this free offer because while undertaking a local air quality measurement it was noticed that higher than average smoke was being emitted by your wood heater. To make sure that there are no safety concerns with your heater/open fireplace and to assist you to minimise smoke coming from your wood fire we encourage you to accept this offer.

To accept this free offer simply call one of the wood heater service professionals listed below and quote the reference number provided at the top of this page. Please note your free flue/chimney clean and safety check will need to be carried out at a time when you are at home and the fire will need to be unlit and cool.

Please note that the chimney sweeping companies have offered their services for this project with the costs being covered by the Firewood Association of Australia. The chimney sweep companies listed are not recommended by the Council above any other chimney sweep company and you may wish to engage your own cleaner at your cost.

This offer expires on 29th August 2014.

If you require any additional information or clarification you are welcome to contact me on 9843 0555, email cbourke@thehills.nsw.gov.au or Alan McGreevy of the Firewood Association of Australia on 1300 131 481 during normal office hours.

Chimney Sweeps / Flue cleaners:

- Sydney Heaters & Pizza Ovens: 1300 938 346.
- The Flue Doctor: 0452 223 583.

Yours faithfully

Craig Bourke
ENVIRONMENTAL HEALTH COORDINATOR

Conducting face-to-face interventions

By the cut-off date of the 29th of August specified in the 'Free Flue Clean' offer letter, a total of 20 households had booked a flue clean with one of the two listed service professionals. The flue cleans were carried out progressively from the 8th August to the 28th of September.

The wood heater service professionals were asked to complete a checklist for each flue clean that they carried out. The checklist was to be filled out after the Condition 2 interventions were completed and in the presence of the homeowner for Condition 1 interventions.

A pro-forma wood fire inspection report checklist is shown on the following page:

FAA
WOOD FIRE INSPECTION REPORT

Date of Inspection; _____

Name: _____ Reference Number: _____

Address: _____

Who normally lights and manages the fire? _____

Heater/fireplace details: _____

Probable cause/s of excessive smoke?

Heater Maintenance	
Build-up of creosote	
Air inlet blocked	
Soot build up	
Ash build up	
Other maintenance issues	
Installation	
Flue/chimney height	
Flue/chimney location	
Other factors affecting draft	
Fuel	
Wood moisture content	
Sleepers/treated/painted wood	
Large piece size	
Wood type/species	
Supplier/Self collected	
Rubbish/incinerator	
Lighting	
Lack of Kindling	
Poor fire build procedure	
Inadequate air flow	
No starting wood	
Operation	
Air vents not open 20 min	
Overfilled fire box	
Lack of coals on refill	
Other cause for operating temperature less than 500^0C	
General Comments	

Phase 3 Project Activities (2105)

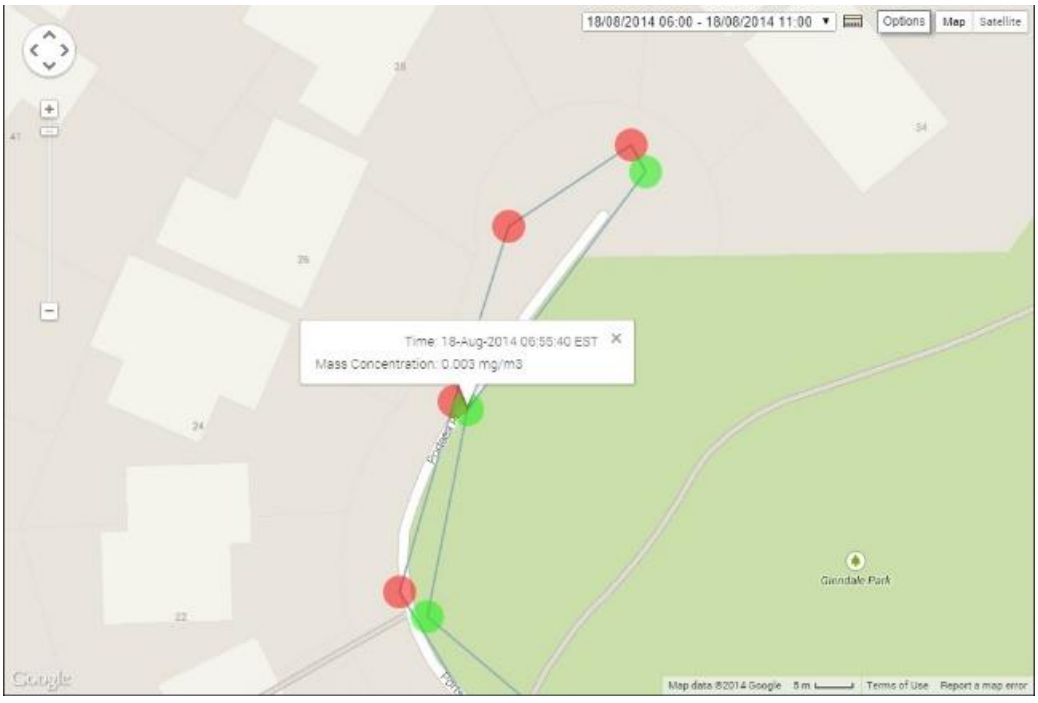
Assessing smoke emissions

Even though the *SmokeTrak* system had been proven to be an efficient means of detecting high smoke emitting households, the highly motile nature of wood smoke means that the system could not be used to assess the level of smoke emissions from the targeted households in this project with an adequate degree of reliability. Under some weather conditions, for example when wind is blowing in a direction that takes the smoke away from the road frontage, even high levels of smoke will not register on the particle analyser in the *SmokeTrak*. Also when the wind direction is fickle and moving smoke around, the density of smoke at street level will be inconsistent, resulting in variable $PM_{2.5}$ readings. Under very still conditions, smoke from a single high emitting household can spread across a wide area, making it difficult to allocate a particular reading to an individual source.

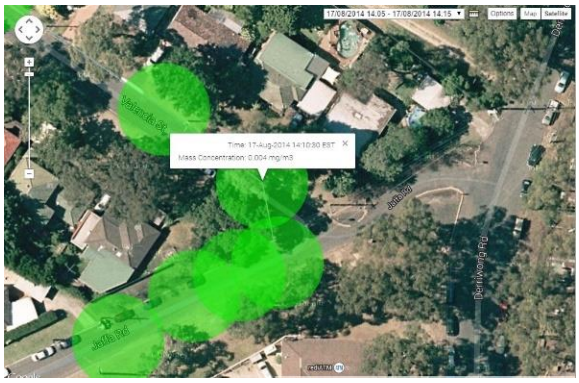
Below are examples of the variability in *SmokeTrak* readings due to the wind effect.

In this example, a light westerly wind was blowing towards the road from the house in this picture. On travelling towards the house the *SmokeTrak* recorded a high smoke reading of 323 micrograms, however just one minute and 35 seconds later at the same location, but travelling in the opposite direction, there was virtually no smoke detected, with a minimal *SmokeTrak* reading of 3 micrograms. The actual amount of smoke being emitted by the wood heater did not alter perceptibly between readings, however the smoke was blown towards the south and away from the road by the fickle breeze.

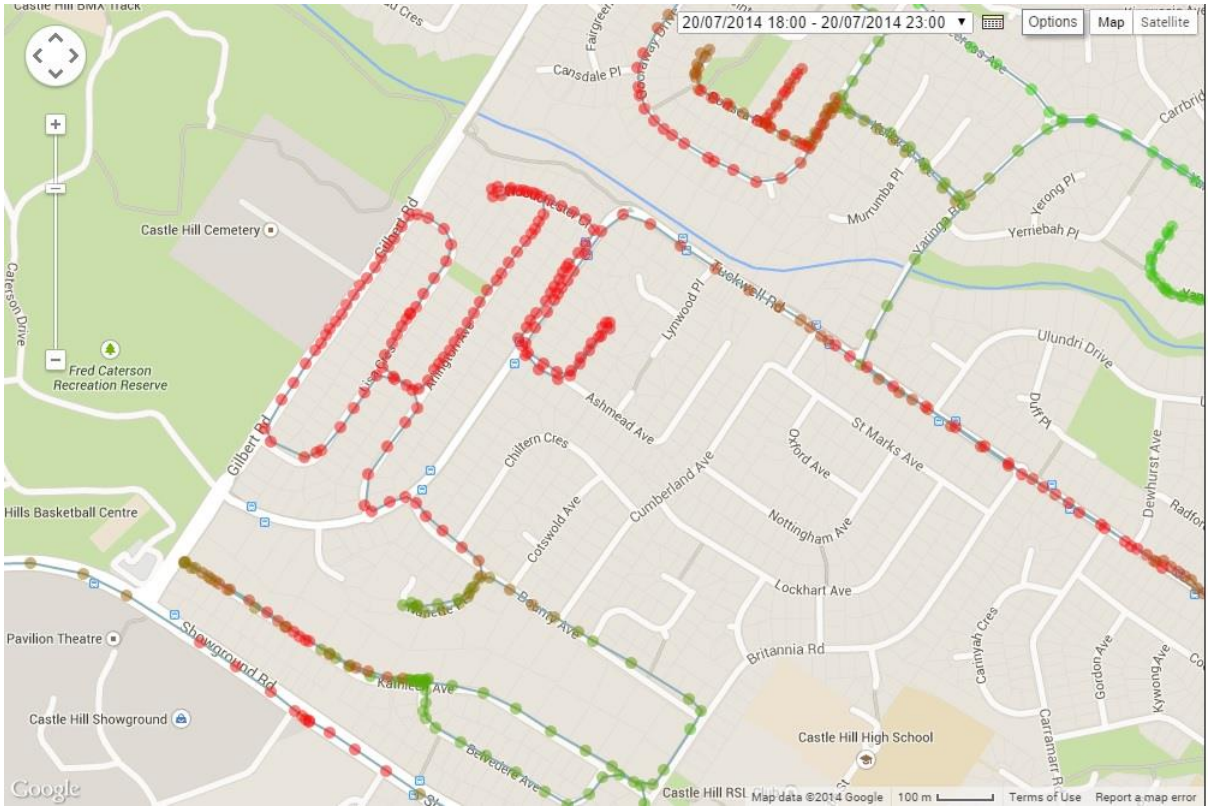
Below are screen shots from the GPS log showing the high reading recorded at 6.54 am and then the low reading from the same source just one minute later at 6.55 am.



In the below example, the photo was taken at the same time as the data shown in the satellite image. The photo shows that the chimney was clearly emitting excessive smoke, however the wind was blowing away from the road at the time, which meant that the *SmokeTrak* did not register any elevated PM2.5 readings.



The below image from the *SmokeTrak* system shows the wide spread of smoke in a section of Castle Hill. Even though several individual households were identified as contributing to the generally elevated level of smoke in the area, under the still wind conditions prevailing at the time it would have been very difficult to ascribe a particular smoke emission level to any individual household by any means other than visual assessment of a smoke plume.



This unavoidable variation and uncertainty in readings caused by the prevailing weather conditions meant that the assessment of household smoke emissions from the targeted intervention and control groups had to be carried out using the visual assessment of individual smoke plumes. In the daytime this was done using natural light, viewing the flue/chimney from as many angles as possible. At night a powerful narrow beam torch, as described earlier in this report, was shone just above the top of the flue or chimney. The torch method provided both a good light intensity and a constant angle of reflection of light from the smoke, providing a reasonably easy and consistent assessment of comparative smoke intensity.

It is worth noting again that the use of a powerful torch in residential areas at night requires considerable care so as not to alarm residents. Provided the precise location of the chimney is known, and the torch has a sufficiently narrow beam, it is possible to minimise the amount of light shining on the roof and surrounding trees, making the night time observations as unobtrusive as possible. Wherever the use of the torch would have been observed by residents, people walking in the street or neighbours, it was not used and no observation was recorded.

Rating smoke emissions

For reasons of consistency with other, previously conducted visual smoke surveys, it was decided to use the Smoke Scale described in the Environment Australia Training Handbook for Wood-Smoke Mitigation[25] to rate each observed smoke level. This scale (referred to hereafter as Todd's Scale) rates smoke emissions from 0 to 5 as follows:

0	No visible indication that heater is operating
1	Heat haze only. Indicates heater is operating
2	Faint smoke
3	Moderate smoke
4	Thick smoke that disperses before reaching the property boundary
5	Very thick smoke which remains visible beyond the boundary of the property

[25] Todd, J.J. (2003). Wood-Smoke Handbook: Woodheaters, Firewood and Operator Practice. For The Natural Heritage Trust, commissioned by Environment Australia and The NSW Environment Protection Agency.

To determine whether a household is emitting an excessive amount of smoke, environment protection agencies and councils generally rely on the following definition. Smoke emissions from a flue are assessed as being excessive when:

> *"a visible plume of smoke extends into the air for a continuous period of not less than 10 minutes, including a period of not less than 30 seconds when the plume extends into the air at least 10 metres from the point at which the smoke is emitted from the flue or chimney."*

This level of smoke is approximately equivalent to No 3 on the Todd Scale shown above.

Photo examples of the Todd's Scale smoke rating system.

Rating 1 – Heat haze only (this fire was operating at the time of this photo)

Rating 2 – Faint smoke

Rating 3 – Moderate smoke

Rating 4 – Thick smoke that disperses before reaching property boundary

Rating 5 – Very thick smoke that remains visible beyond the property boundary

Additional interventions

By mid-July 2015 it became obvious that some households in all three experimental conditions were still regularly emitting excessive smoke. In collaboration with The Hills Shire Council it was decided to carry out a further, additional intervention to a selection of these recalcitrant, high emitting households to see if they could be motivated by a more forceful direction from the Council.

This supplementary intervention was designed to deliver a clear instruction to the householder that they needed to take positive steps to amend their wood heater operation practices in order to avoid prosecution. This intervention took the form of a personalised letter from Council to the occupier, with an invitation to contact the Council for clarification or assistance.

Eight households were selected from the surveyed population based on their observed emissions during surveys conducted in June and July 2015. Two of the most frequent emitters from Condition 1, two from Condition 2, and four from Condition 3 were sent a follow-up letter. The letters were worded appropriately to reflect the specific intervention that each household had received in 2014.

Pro-forma copies of the letters follow:

THE HILLS SHIRE COUNCIL
3 Columbia Court, Baulkham Hills NSW 2153
PO Box 7064, Baulkham Hills BC NSW 2153
Telephone +61 2 9843 0555
Facsimilie +61 2 9843 0409
DX 9966 Norwest
Email council@thehills.nsw.gov.au
www.thehills.nsw.gov.au
ABN No. 25 034 494 656

31 July 2015

Our Ref:

Dear Mr & Mrs

Excessive Wood Smoke from -

It has been brought to my attention to that excessive smoke is being emitted from a wood heater located on the above mentioned property. Excess smoke has been noted on a number of occasions this winter.

I note that this matter was raised with you last year and at that time you were invited to participate in a program in which you were provided a free of charge flue / chimney clean which included advice from the contractor on the best operating procedure for the heater.

You are required to take appropriate action to reduce the amount of smoke emitted from the heater. To assist you I am available to discuss this matter or meet with you on site.

Your prompt attention to this matter is appreciated.

Failure to minimise excess smoke may result in the issue of a Smoke Abatement Notice or other regulatory action.

If you require any additional information or clarification in regards to this matter please contact me on 9843 0287 during normal business hours or email, cbourke@thehills.nsw.gov.au.

Yours faithfully

Craig Bourke
ENVIRONMENTAL HEALTH COORDINATOR

THE HILLS
Sydney's Garden Shire

THE HILLS SHIRE COUNCIL
3 Columbia Court, Baulkham Hills NSW 2153
PO Box 7064, Baulkham Hills BC NSW 2153

Telephone +61 2 9843 0555
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Email council@thehills.nsw.gov.au
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ABN No. 25 034 494 656

31 July 2015

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You are required to take appropriate action to reduce the amount of smoke emitted from the heater. To assist you I am available to discuss this matter or meet with you on site.

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ENVIRONMENTAL HEALTH COORDINATOR

THE HILLS
Sydney's Garden Shire

THE HILLS SHIRE COUNCIL
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Yours faithfully

Craig Bourke
ENVIRONMENTAL HEALTH COORDINATOR

These follow-up letters prompted most of the recipients to contact the Council by phone. One recipient requested a visit by Council to check the moisture content of the wood they were burning. This visit was carried out on 11 August 2015 by Craig Bourke from The Hills Shire Council accompanied by Alan McGreevy from the FAA. The moisture content of the wood being burnt by the householder was tested during the visit and found to be in the 14-18% range, which is acceptable. The household's heater was inspected and found to be in good order. The flue on this heater had been cleaned in August 2014 as a part of the Free Flue Clean offer. This indicated that the smoke problem was caused by incorrect burning practices. It is worth noting that this householder mentioned that the heater was kept alight for most of the day and night during winter and was regularly refuelled by his teenage children.

Evaluating Post Intervention Emissions

The two main objectives of this project are the reduction of nuisance smoke emissions from domestic wood heaters i.e. those that are severe enough to stimulate a negative reaction from neighbouring residents, as well as an improvement in local area air quality.

The actual concentration and duration of smoke emissions that would be likely to inconvenience a nearby neighbour, or make a noticeable impact on local air quality depends on a number of factors, such as the direction and strength of wind, topography, flue height and location, distance to neighbouring residences etc.

Heat haze (Todd's Scale 1) and very light smoke (Todd's Scale 2) are not likely to create any great nuisance to neighbours or contribute significantly to neighbourhood smoke levels. Also, short duration or infrequent smoke emissions during heater start up and refuelling are usually tolerated by neighbours and mostly disperse in a short time. Short duration exposure to high levels of smoke from biogenic sources such as wildfires and fuel reduction burns is a generally accepted part of life in Australia. Even though all wood fires will emit some smoke at times, it is mostly when people have to endure smoke from neighbour's wood fire for prolonged periods or on a frequent basis that they will feel the need to complain. From an environmental health viewpoint, the frequency and duration of exposure to wood smoke are two of the main measures used to assess the potential for health impacts. Prolonged high emissions of wood smoke into an air shed can overwhelm the natural tendency of smoke to disperse, creating pockets of dense smoke that can exceed acceptable levels.

We therefore determined that the best measure for rating smoke emissions as "excessive" or unacceptable, is the number of times (frequency) that an individual wood fire emits sufficient smoke to be likely to have a noticeable impact on neighbouring residences or on the smoke levels of an air shed. This equates approximately to smoke levels at Todd Scale 3 or more.

By regularly checking, and rating the smoke emissions from the targeted households as well as the control group throughout the winter of 2015, we were able to assess the effectiveness of each of the intervention strategies.

Absolute comparison of the frequency of smoke emissions that occur over different time periods is not a valid measure of heater operation, because wood heater use is highly dependent on a number of conditions. For example, a high number of smoke observations in early July compared to later in the month may simply be because early July was colder and/or wetter than late July and the wood fires in the observed households were alight more often. Wood fire usage is also far more frequent on weekends than it is during week days. Special occasions that encourage social gatherings, such as the State of Origin Rugby League series, can also influence the decision of householders to light their fires.

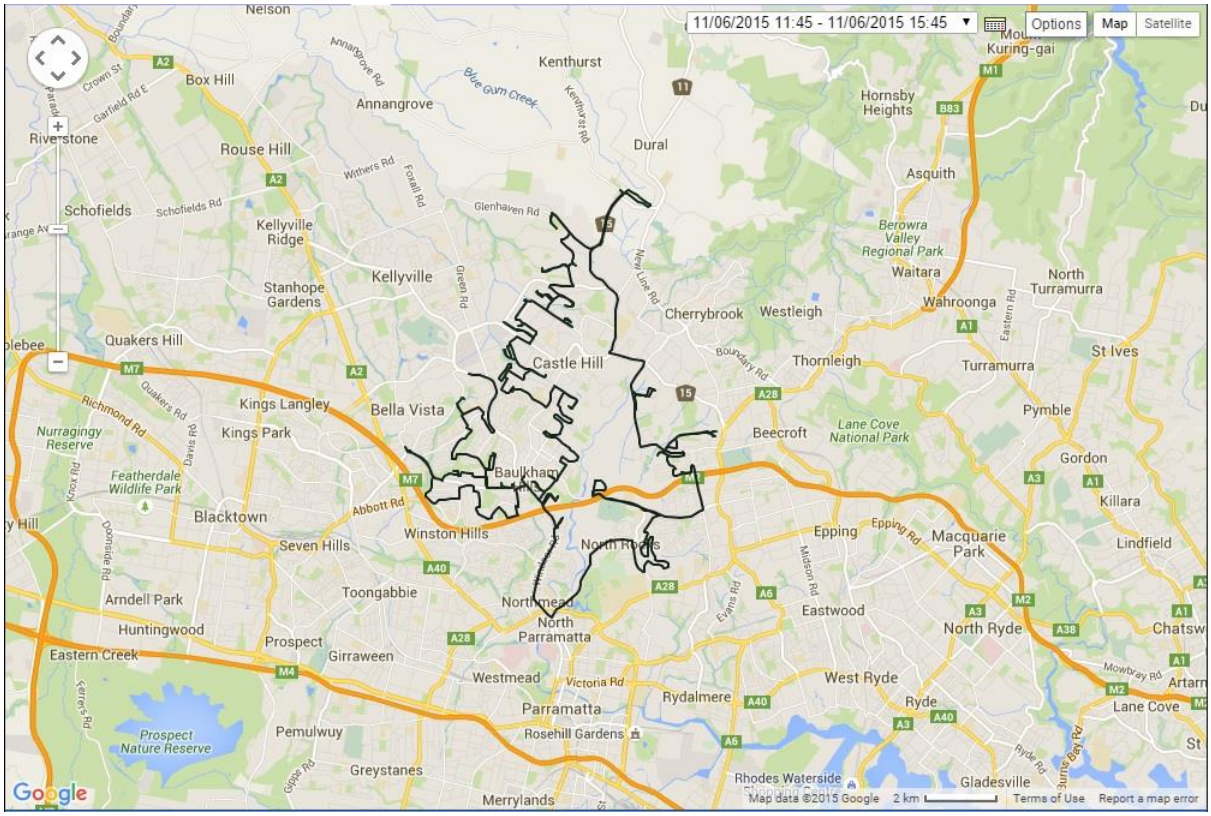
Because we assessed the control group with the same frequency and at approximately the same times as the households in the experimental conditions, we were able to reliably compare the mean effectiveness of each condition against the control group under similar environmental and social conditions.

One acknowledged limitation to the assessment of post intervention smoke emissions during this project is that, due to limited finances, the smoke observations had to be carried out by operators who were potentially aware of the experimental conditions that were applied to each household. Even though every attempt was made to be objective and consistent with the application of smoke ratings, it is accepted that the observations were not conducted under ideal "double blind" conditions.

TABLE OF POST INTERVENTION OBSERVATION DATES IN 2015

Date	Time	Date	Time	Date	Time
10/06/2015	Evening	04/07/2015	Evening	10/08/2015	Evening
11/06/2015	Morning	05/07/2015	Morning	11/08/2015	Morning
11/06/2015	Afternoon	05/07/2015	Afternoon	11/08/2015	Evening
11/06/2015	Evening	05/07/2015	Evening	12/08/2015	Morning
12/06/2015	Morning	06/07/2015	Morning	12/08/2015	Evening
12/06/2015	Evening	06/07/2015	Evening	13/08/2015	Morning
13/06/2015	Morning	07/07/2015	Morning	21/08/2015	Evening
15/06/2015	Evening	12/07/2015	Evening	22/08/2015	Morning
16/06/2015	Morning	13/07/2015	Morning	23/08/2015	Morning
16/06/2015	Evening	13/07/2015	Evening	23/08/2015	Midday
17/06/2015	Morning	14/07/2015	Morning	23/08/2015	Afternoon
17/06/2015	Evening	14/07/2015	Afternoon	23/08/2015	Evening
18/06/2015	Morning	14/07/2015	Evening	24/08/2015	Morning
18/06/2015	Morning	15/07/2015	Morning		

Travel route for post-intervention smoke surveys



Attrition

During the period of time over which this field trial was conducted, one of the houses in the control group was sold and vacated another house in this group remained unoccupied throughout the entire 2015 observation period. This meant that the total number of households that remained in the study at the end of the survey period was 58.

RESULTS AND DISCUSSION

During the face-to-face interventions the wood heater service professionals were asked to complete a checklist for each flue clean that they carried out. The checklist was to filled out after the Condition 2 interventions were completed and in the presence of the homeowner for Condition 1 interventions. A summary of the information recorded by the wood heater service professionals on the 20 completed checklists is provided below.

Type and age of heater

Make	Model	Approximate age
Lopi	Endeavour	7 years
Lopi	Endeavour	n/a
Lopi	Heritage	12 years
Lopi	Liberty	5 years
Lopi	Answer	n/a
Kemlan	n/a	20 years
Kemlan	Double Side	15 y/o
Kemlan	Supa Nova 32	n/a
Norseman	Conture	n/a
Austwood	Wentworth	12 years
Turbo 10	Hi tech	n/a
Turbo 10	n/a	30 years
Osburn	2200	n/a
Osburn	1000	20 years
Heatcharm	I 500 inbuilt	n/a
Heritage	Woodland	15 years
Nectre	n/a	n/a
Masport	Grandview	4 years
Jindara	Inbuilt	n/a
Eureka	n/a	20 years

Heater maintenance issues

Issue	Yes	Slight	No
Build-up of creosote	7	2	11
Air inlet blocked	3	4	13
Soot build-up	13	2	5
Ash build-up	11	1	8
Other maintenance issues	4*		16

* Other maintenance issues that were noted were: - Heater/flue not cleaned since installation (12 years); Last flue clean was incomplete leaving blockage at bend; Ash from last flue clean left on baffle; Cowl had rusted and collapsed, blocking the flue.

Installation issues

Issue	Yes	No
Flue/Chimney height*	13	7
Flue/chimney location	1**	19
Other	7**	13

* AS/NZS 2918-2001 specifies a minimum flue height of 4.6 metres above floor level. A flue length of 4.5 metres is generally considered to be the minimum necessary to achieve adequate draft in a wood heater. Other factors such as roof pitch, house site, surrounding structures and trees can necessitate greater flue height. (see pictures below). Some local government authorities have set specific flue height and location requirements to protect neighbouring residents from smoke exposure. For example, The Hills Shire has a policy that requires flues to exhaust at least 1 metre above any structure that is within a 15 metres horizontal radius.

** Other installation issues that were noted were: - Chimney below ridge line; Anti-downdraft cowl required due to property terrain; Undersize flue (5 inch) with large bend; Top baffle restricting draft; Surrounding trees impacting air movement (x3); Sharp bend in flue below roof penetration.

Comment on flue length and chimney height

The terms flue and chimney are often used interchangeably. The flue is the working part of a chimney, conveying the products of combustion safely to the atmosphere. The chimney includes the shaft within which the flue is housed.

This is an example of an under-height chimney/under-length flue emitting excessive smoke. The house is situated in a cut (photo was taken from road level) and there are also surrounding trees causing wind eddies and downdraft.

Flues and chimneys operate on the principle that hot air rises because it is less dense than cold air. When a flue is filled with hot gas, that gas tends to rise because it is less dense than the air outside the house. The rising hot gas creates a pressure difference called draft which draws combustion air into the appliance and expels the exhaust gas outside. Even when a fire is not lit, the lower air pressure at the top of a flue compared to the air pressure at the bottom end will create a draft which assists in the lighting of the fire.

Two factors affect the amount of draft produced by a chimney:

1. Heat: the hotter the gases in the chimney compared to the air outside, the stronger the draft.
2. Height: the taller the chimney, the more draft it will produce at any given temperature difference.

Building Code of Australian (BCA) flue and chimney height regulations

Chimneys need to be high enough to ensure that smoke is directed away from where it might be harmful to neighbours.

The current BCA states that chimney openings need to be at least 300mm higher than the highest part of any roof within 3.6 metres of the chimney. Flues need to be 600mm higher than the highest part of the roof within 3 metres. Flues that are more than 3 metres away from the highest part of the roof need to be 1000mm above the roof penetration.

Even though this flue is probably more than the required height above floor level it is obviously located too close to a window and is well below the ridge line on this steep pitched roof.

Wood fuel issues

Issue	Yes	Some	No	Unknown
Wood moisture > 25%		2	12	6
Painted/treated wood		2	18	
Old rail sleepers		1	19	
Oversize pieces		1	19	
Softwood	2	1	17	
Rubbish incinerator			20	

Principle wood source

FAA member	6
Other wood supplier	3
Self-collected	9
Unknown supply source	2

Note: Most surveys on wood sourcing in Australia have reported that approximately 50% of wood users purchase their wood and 50% self-collect. This small sample conforms to this pattern.

Fire lighting and operating issues

Issue	Yes	No	Not assessed
No kindling	0	13	7
Poor fire starting technique	0	12	8
Inadequate air flow on start up	10	4	6
Lack of small split starting wood	0	10	10
Air vent closed prematurely after reloading	12	3	5
Fire box overfilled	1	14	5
Lack of heat (hot coals) on refuel	3	12	5
Other causes for fire running below correct operating temperature of 500^0C*			

* Comments made in this section of the checklist by the wood heater service professionals all referred to the issues already mentioned in other sections.

Feedback from the service professionals

At the completion of the intervention program the two wood heaters service companies that carried out the face-to-face interventions were asked to provide feedback on the program.

The Flue Doctor

> *I found the trial we ran was a great success. The response I received from people was always positive. People asked questions and were prepared to change poor maintenance and burning habits once they were shown the right way to use a fire. Some had not been advised by installers/sellers or read manuals, some people were not aware of these things for years, which were the main reasons for smoke emissions – poor use of air vents, keeping flues clean, burning dry/seasoned quality hardwood, keeping wood under cover.*
>
> *I think the education process could be repeated successfully with different councils, perhaps even provided as a 'training' regime as part of council practice for people that purchase new wood fires or buy a house that has an existing fireplace.*
>
> *I have had people in the trial request that I clean and inspect their fireplaces every year now. I have also done maintenance to fireplaces that will make them last longer and draw better (flue extensions, repaired flues and crowns, replaced baffle plates).*
>
> *I feel privileged to be a part of this exercise. I am passionate about this issue of emissions from a financial and environmental perspective. I know wood fires used correctly have a place in suburban and rural households indefinitely – there is no better source of energy for heating.*
>
> *David Papandrea*
> *The Flue Doctor*

Sydney Heaters & Pizza Ovens

As a major local supplier and installer of wood heaters in The Hills Shire we were pleased to be able to participate in the smoke reduction project. From a commercial point of view, we expect to receive repeat business from our role in the program. We did not experience any negative outcomes or feedback from delivering the flue cleaning and training activities for the project and we found that the free flue clean offer was well received by all participants. Most of the householders were actually very interested in learning how to reduce their smoke emissions and feedback was generally positive.

We found that the main issue in the houses we visited was poorly maintained heaters. Surprisingly we found that most householders had a reasonably good understanding of the causes of wood smoke, but poor operating habits appear to have become deeply ingrained in some people which may mean that they are resistant to change.

We understand that circumstances prevented the free clean offers from being sent out until late in the season but it would have been better from our perspective if the letters were sent out earlier in the wood heating season.

We would be most willing to participate in any future programs of this nature as we firmly believe that wood fires are simply the best form of domestic heating available and we are keen to ensure that our customers can continue to enjoy their wood fires without annoying their neighbours.

Yours sincerely
Peter Petersen
Sydney Heaters Pty Ltd

Comment on face-to-face intervention observations

The face-to-face interventions carried out during this phase of the project highlighted two main factors that appear to be the cause of most of the excessive wood smoke emissions in the participating households.

First, 70% of the high emitting wood heaters had an under length or incorrectly located flue. Second, there was a notable lack of understanding of the maintenance, cleaning and operating requirements of wood heaters. The person-to-person interactions highlighted the fact that many enthusiastic wood heater owners are simply not aware of the available information on correct wood heater operation. Feedback from the wood heater professionals who carried out the interventions indicated that most wood heater operators are highly receptive to information and instruction on the correct use of their wood fires, when delivered in this way.

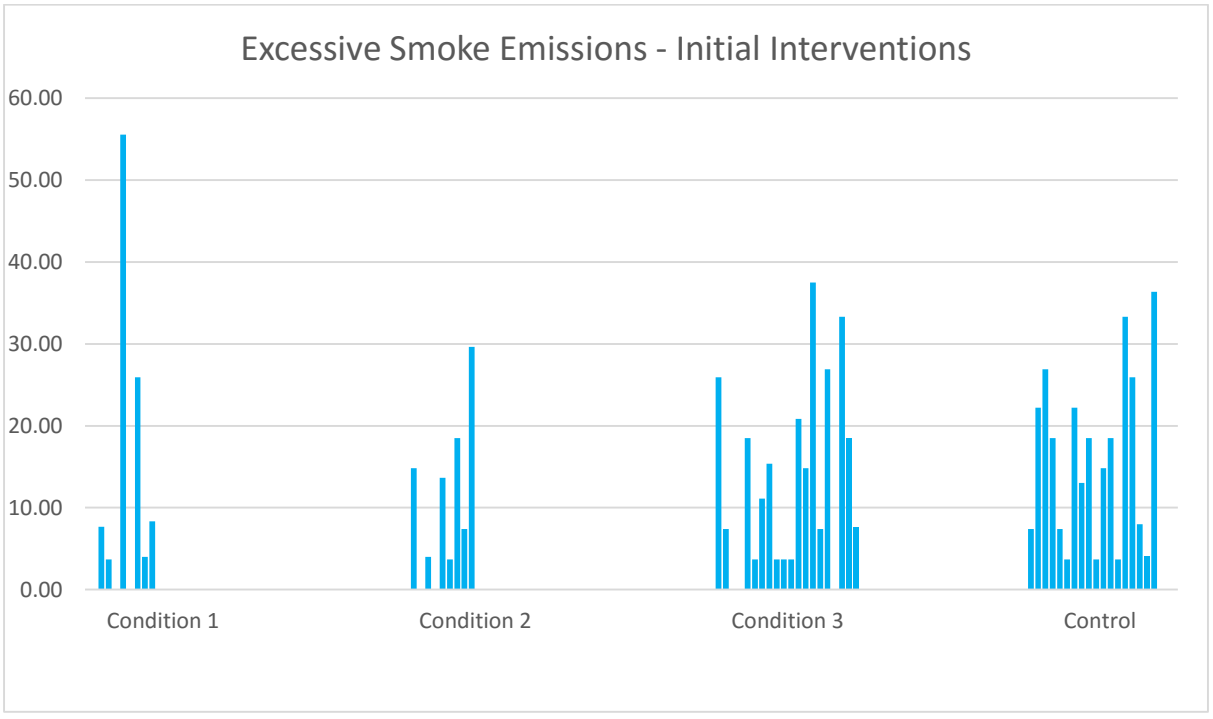
In any hierarchy of control measures, the use of an "engineered" solution to a problem is always desirable because it does not rely on human behaviour change for its success. The large number of incorrectly installed heaters noted by the service professionals indicates that this is a significant factor in the generation of excessive emissions. Therefore, it is likely that a program to address installation problems in high emitting households would result in a meaningful reduction in problematic emissions.

Incorrect operation and maintenance of wood heaters has been recognised as a major cause of excessive smoke emissions for many years, and education on the lighting and operation of wood fires has been the main focus of most previous wood smoke reduction campaigns. This finding from the face-to-face interventions indicates that both the wood heating industry, and the environmental health sector have not succeeded in ensuring that all people who have a wood fire know how to operate it correctly, and that simple information on correct fireplace operation is readily available.

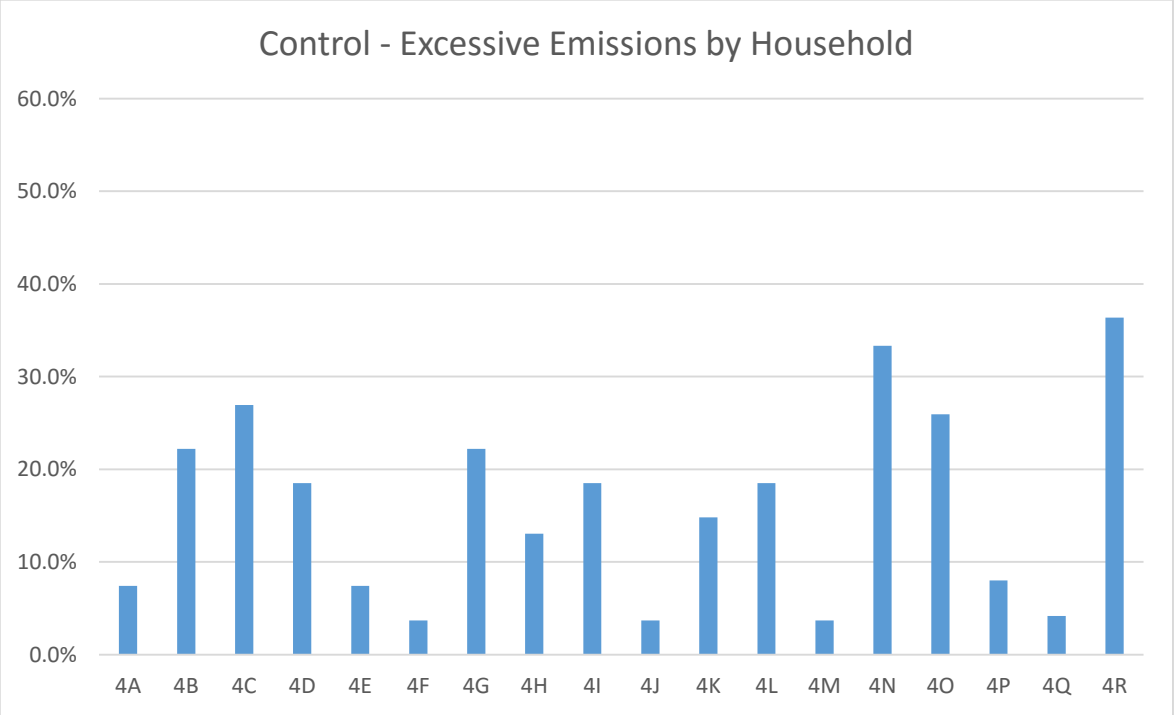
Post Intervention Smoke Observations

By the commencement of the 2015 wood heating season all of the households in this study, excluding the control group, had received their initial intervention. Condition 1 households had received a free flue clean and heater inspection as well as instruction and advice on wood heater operation practices. Condition 2 households had received a free flue clean and heater inspection. For both of these groups, any repairs or maintenance recommended by the heater service professionals had been completed before the start of the 2015 winter. Condition 3 households would have had adequate time to carry out any repairs or change their wood supply source before the start of the 2015 season, if they were motivated to take action to reduce their emissions by the "friendly" flue clean offer notice issued by Council.

As noted earlier in this report, all wood fires will emit some smoke occasionally, for example during start up and after reloading. We therefore determined that the most appropriate measure of the effectiveness of the interventions carried out during this project was the frequency of 'excessive' smoke emissions i.e. smoke emissions of 3 or more on the Todd Scale. Households who were not emitting excessive amounts of smoke for 90% or more of the observations were assessed to be operating their wood fires to an acceptable standard. We rated the delivered intervention to have been 'effective' for these households. Where excessive smoke was noted during 10% or more of the conducted observations, we rated the intervention to have been 'not effective'. To account for variability in wood heater use caused by factors such as the prevailing weather conditions, (temperature, wind, rain) and for other factors, such as day of the week and time of observation (morning, day or evening) we compared the excessive emissions from the houses who received intervention with the excessive emissions from the Control group, at similar times on the same days.



Analysis of smoke observations from Control Group households

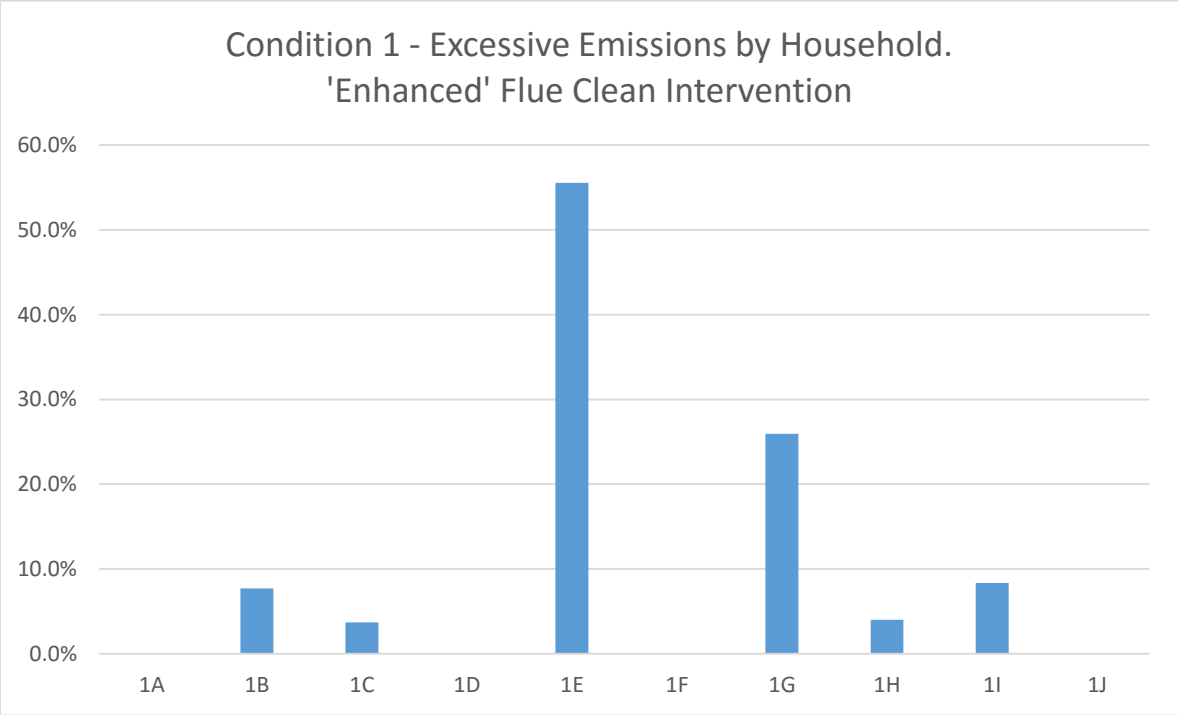


Control Group (No intervention) - Low frequency emitters (<10%)			
House Code	***Excessive***	***Observations***	***Excessive %***
4A	2	27	7.4%
4E	2	27	7.4%
4F	1	27	3.7%
4J	1	27	3.7%
4M	1	27	3.7%
4P	2	25	8.0%
4Q	1	24	4.2%
Mean excessive emission frequency for low emitters[(a)]			***5.4%***

Control Group (No intervention) - High frequency emitters (>10%)			
House Code	***Excessive***	***Observations***	***Excessive %***
4G	6	27	22.2%
4H	3	23	13.0%
4I	5	27	18.5%
4K	4	27	14.8%
4B	6	27	22.2%
4C	7	26	26.9%
4D	5	27	18.5%
4L	5	27	18.5%
4N	9	27	33.3%
4O	7	27	25.9%
4R	8	22	36.4%
Mean excessive emission frequency for high emitters[(b)]			**22.8%**
Overall mean – Control group excessive emission frequency[(c)]			**16.0%**

Of the 18 households that remained in our Control group after attrition - 39% (seven households) did not emit excessive amounts of smoke on more than 10% of the times that they were observed. The mean of the excessive emissions events[(a)] for this lower emitting population in the Control group was 5.4%. The remaining 61% of households within the Control group[(c)] emitted excessively on more than 10% of the times that they were assessed. The mean of the excessive emission events for this higher emitting population was 22.8%. It is worth noting that every household within the Control group emitted excessive smoke on at least one occasion during the period of assessment.

Analysis of smoke observations from Condition 1 households following initial intervention



Condition 1 Households – Enhanced Flue Clean Intervention Effective (< 10% excessive)			
House Code	***Excessive***	***Observations***	***Excessive %***
1A	0	27	0.0%
1B	2	26	7.7%
1C	1	27	3.7%
1D	0	27	0.0%
1F	0	27	0.0%
1H	1	25	4.0%
1I	2	24	8.3%
1J	0	25	0.0%
Mean excessive emission frequency[(d)]			***3.0%***

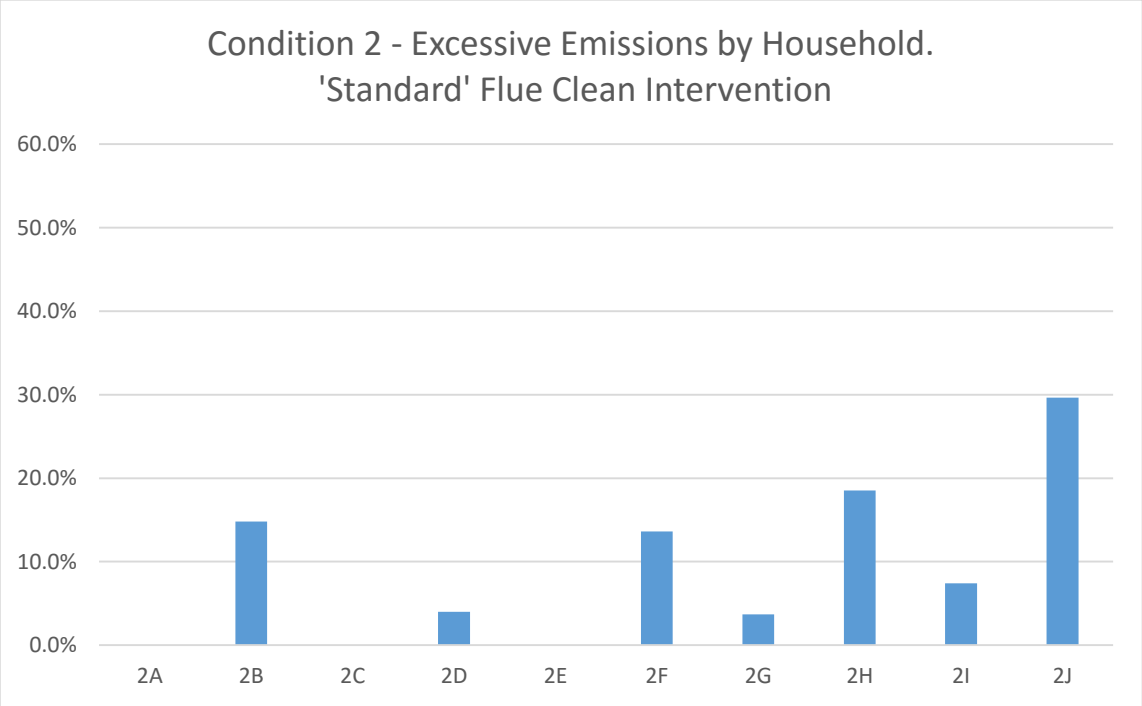
Condition 1 Households – Enhanced Flue Clean Intervention Not Effective (> 10% excessive)			
House Code	***Excessive***	***Observations***	***Excessive %***
1G	7	27	25.9%
1E	15	27	55.6%
Mean excessive emission frequency[e]			***40.8%***

Of the 10 households in Condition 1 who received an Enhanced Flue Clean intervention; i.e. instruction and advice on the operation and maintenance of a wood heater as well as a flue clean, 80% ceased emitting excessively as a result of the initial intervention. The mean excessive emission percentage for the households in this group (who responded positively to the intervention and reduced their emissions) was 3.0%[d] compared to the mean excessive emissions for the entire Control group (under the same conditions) of 16.0%[c]. A two sample t-test showed that there was a statistically significant difference between the means of the two groups (t Stat = 3.4, t critical two tail 2.1). This result confirmed that under the same experimental conditions a substantial reduction in smoke emissions was achieved by 80% of the Condition 1 group as a result of the Enhanced Flue Clean intervention strategy.

The two households in Condition 1 who did not appear to alter their operating practice as a result of the initial intervention continued to emit very excessively with a mean frequency of 40.8%[e]. This is greater than the mean excessive emission frequency for the higher emitters within the Control of 22.8%[b].

It is interesting to note that 50% of the households in Condition 1 who reacted positively to the enhanced flue clean intervention were not observed to be emitting excessively on any occasion during this period of assessment.

Analysis of smoke observations from Condition 2 households following initial intervention



Condition 2 Households – Flue Clean Intervention Effective (< 10% excessive)			
House Code	***Excessive***	***Observations***	***Excessive %***
2A	0	26	0.0%
2C	0	26	0.0%
2D	1	25	4.0%
2E	0	27	0.0%
2G	1	27	3.7%
2I	2	27	7.4%
Mean excessive emission frequency[f]			2.5%

Condition 2 Households – Flue Clean Intervention Not Effective (>10% excessive)			
House Code	***Excessive***	***Observations***	***Excessive %***
2B	4	27	14.8%
2F	3	22	13.6%
2H	5	27	18.5%
2J	8	27	29.6%
Mean excessive emission frequency[g]			19.0%

The households in Condition 2 (Standard flue clean) also showed a marked reduction in excessive emissions with 60% not emitting excessively following the initial flue clean intervention by the wood heater service professional.

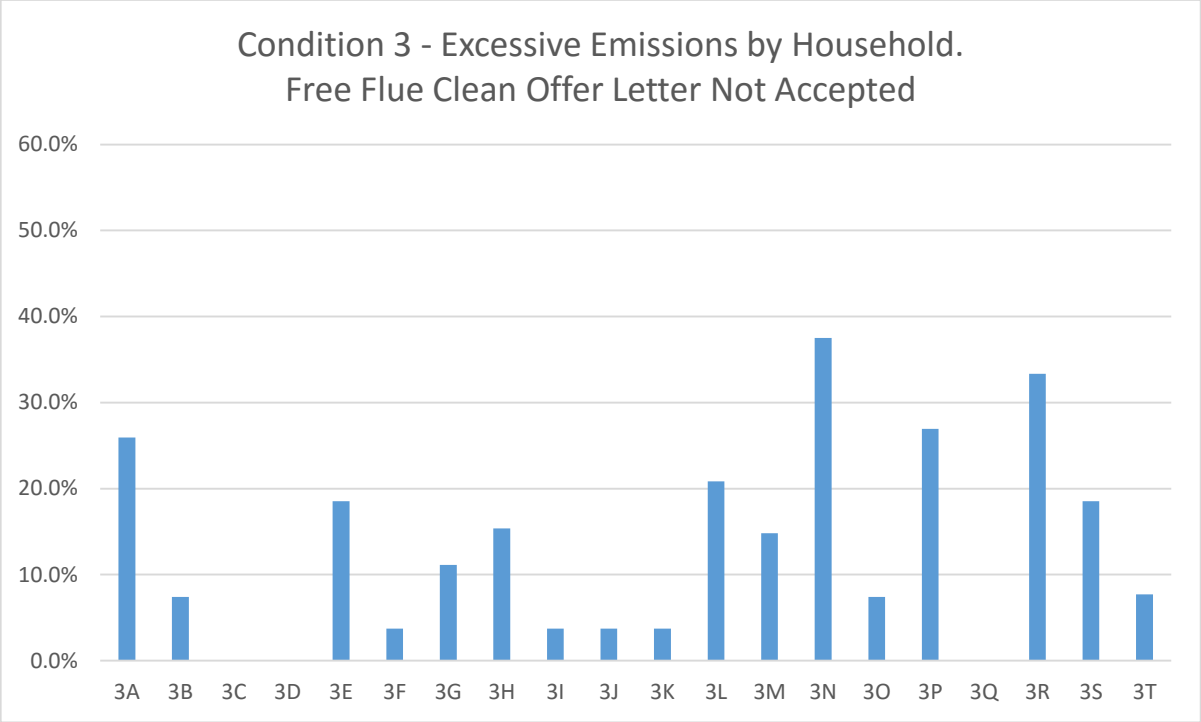
The mean excessive emission frequency of the households in this group who responded positively to the intervention was 2.5%[(f)] compared to the Control group mean[(c)] of 16%. A two sample t-test showed that there was a statistically significant difference between the means of the two groups (t Stat = 3.1, t critical two tail 2.1). This result confirmed that, under the same experimental conditions, a substantial reduction in smoke emissions by 60% of the Condition 2 group was achieved as a result of the standard Flue Clean intervention strategy.

The four households in this group who did not respond effectively to the standard flue clean intervention continued to emit excessively with a mean of 19%[(e)] which is approximately the same as the higher frequency emitters in the Control groups who had a mean excessive emission frequency of 22.8%[(b)].

In addition, it was found that the combined means for the Condition 1 and Condition 2 persistent high emitters was 26.3% which is not significantly different to the mean excessive emission frequency for the high emitters in the Control group of 22.8%[(b)] (t Stat = 0.5, t critical two tail = 2.5).

Analysis of smoke observations from Condition 3 households following initial intervention

One half of the households in Condition 3 (Flue clean offer not accepted) showed an improvement in emissions following the receipt of the letter from Council advising them that they were emitting excessive wood smoke.



Condition 3 Households – Flue Clean Letter Effective (<10 % excessive)			
House Code	***Excessive***	***Observations***	***Excessive %***
3B	2	27	7.4%
3C	0	27	0.0%
3D	0	25	0.0%
3F	1	27	3.7%
3I	1	27	3.7%
3J	1	27	3.7%
3K	1	27	3.7%
3O	2	27	7.4%
3Q	0	27	0.0%
3T	2	26	7.7%
Mean excessive emission frequency[(h)]			3.7%

Condition 3 Households – Flue Clean Letter Not Effective (>10% excessive)			
House Code	***Excessive***	***Observations***	***Excessive %***
3A	7	27	25.9%
3E	5	27	18.5%
3G	3	27	11.1%
3H	4	26	15.4%
3L	5	24	20.8%
3M	4	27	14.8%
3N	9	24	37.5%
3P	7	26	26.9%
3R	9	27	33.3%
3S	5	27	18.5%
Mean excessive emission frequency[(i)]			22.0%

The mean excessive emissions frequency of the households within in this group who responded positively to the intervention was 3.7%[(h)] compared to the Control group mean frequency of 16%[(c)]. A two sample t-test showed that there was a significant difference between the means of the two groups (t Stat = 3.6, t critical two tail 2.1). This confirms that under the same experimental conditions there was a significant reduction in smoke emissions by 50% of the Condition 3 group as a result of the Council letter notifying them that they were emitting excessive smoke.

The households in Condition 3 who did not appear to alter their operating practice as a result of the initial intervention continued to emit excessively with an average frequency of 22.0%[(i)], which was not significantly different to the mean emissions from the high frequency emitters in the Control group[(b)] of 22.8% (t Stat = -0.1, t critical two tail = 2.1)

In summary, the interventions carried out in 2014 resulted in substantial to moderate reductions in excessive emissions, depending on the intervention carried out.

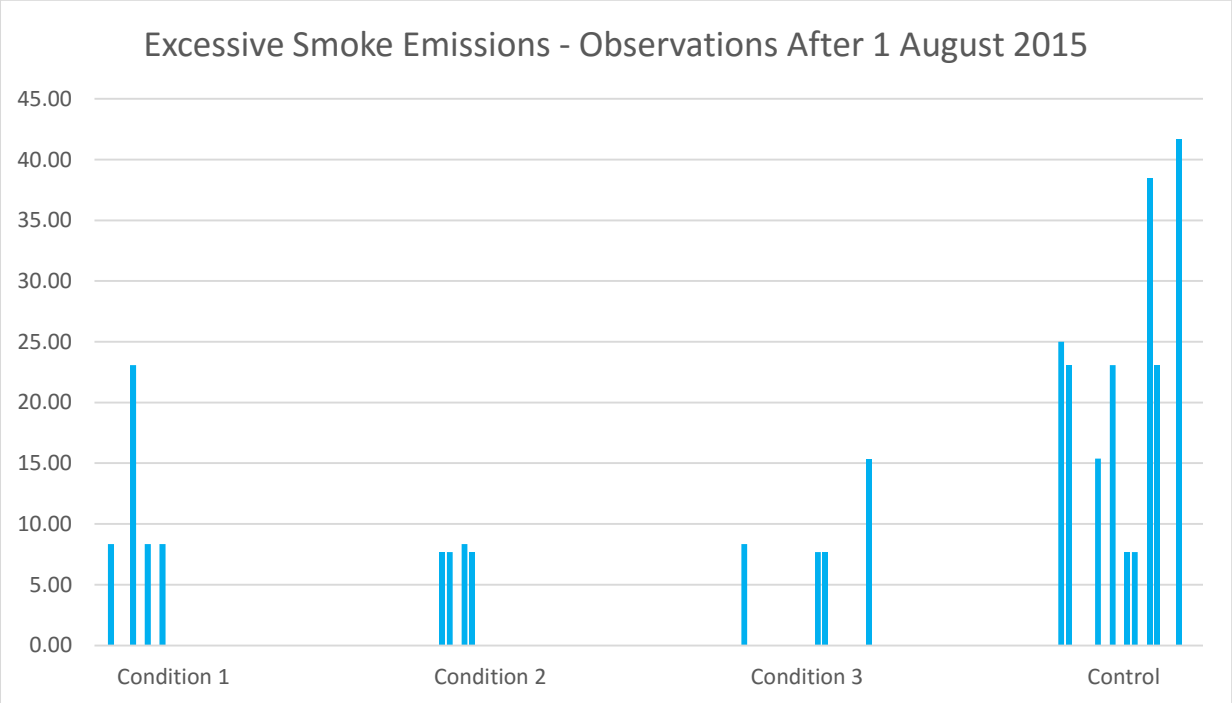
Post Additional Intervention Smoke Observations

As noted earlier in this report, by mid-July 2015 it became obvious that some households in all three experimental conditions were still regularly emitting excessive smoke. Therefore, in collaboration with The Hills Shire Council it was decided to carry out a further, additional intervention to a selection of these recalcitrant, high emitting households to see if they could be motivated by a more forceful directive from the Council.

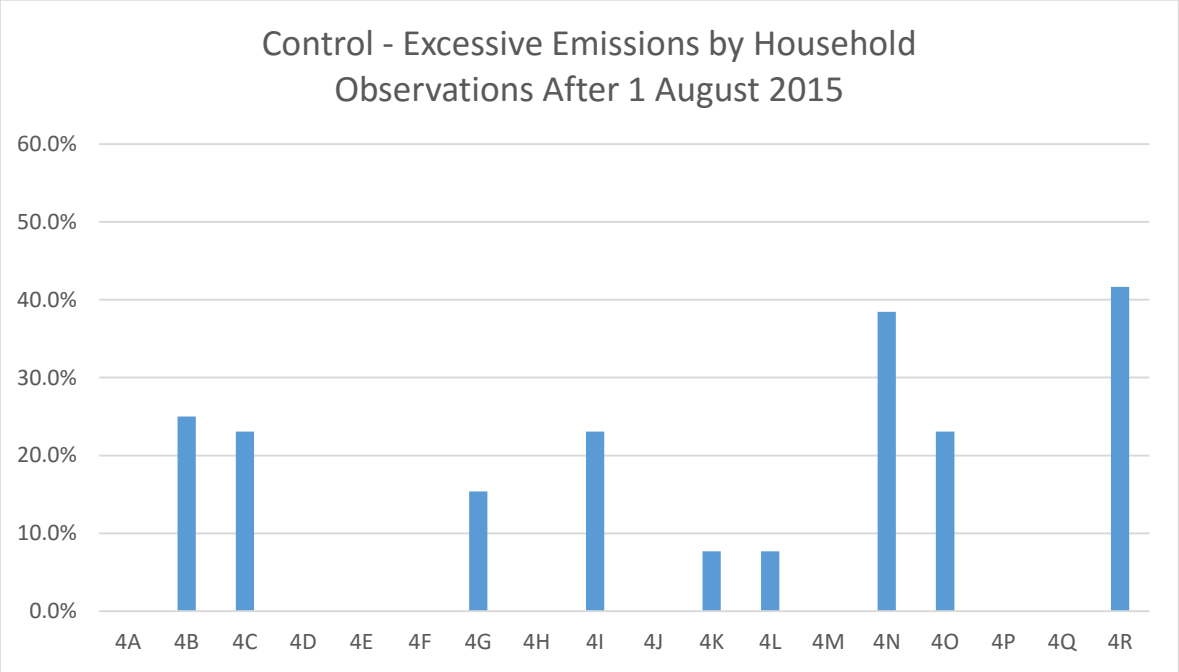
On 1 August 2015 a selection of the highest emitting households in each experimental group being studied was sent a personalised letter that referred to the type of intervention they had received in 2014 i.e. Condition 1 - enhanced flue clean, Condition 2 - standard flue clean, and Condition 3 – free flue clean offer. This letter from the Council contained a direct instruction to the householder requiring them to take appropriate action to reduce the amount of smoke emitted by their wood heater and notified the householder that they could face prosecution if they failed to respond.

The smoke emissions of all households in the study, including the households who did not receive this additional intervention letter, were then recorded until 24 August 2015 by which time the weather had warmed sufficiently to make heater use infrequent.

By adopting the same metric as we applied to the pre-1 August 2015 interventions the secondary intervention letter was found to be highly effective.



Analysis of smoke observations from Control Group households after follow-up intervention

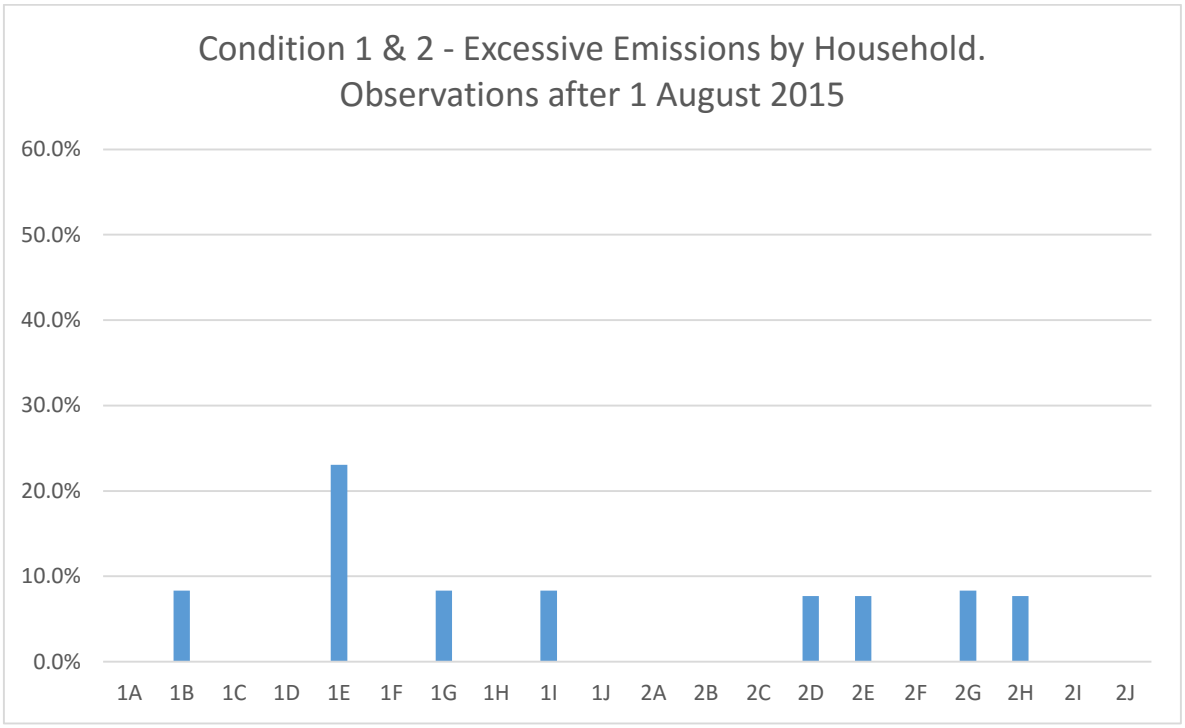


Control Group Observations – Lower frequency emitters (<10% excessive)				
House Code	***Excessive emissions after 1 August***	***Observations after 1 August***	***Excessive % after initial intervention***	***Excessive % after follow-up intervention***
4A	0	12	7.4%	0.0%
4D	0	13	18.5%	0.0%
4E	0	13	7.4%	0.0%
4F	0	13	3.7%	0.0%
4H	0	13	13.0%	0.0%
4J	0	13	3.7%	0.0%
4K	1	13	14.8%	7.7%
4L	1	13	18.5%	7.7%
4M	0	13	3.7%	0.0%
4P	0	12	8.0%	0.0%
4Q	0	12	4.2%	0.0%
Mean excessive emission % for low frequency emitter[j]			***5.4%***	***1.4%[(i)]***

Control Group Observations – Higher frequency emitters (>10% excessive)				
House Code	***Excessive emissions after 1 August***	***Observations after 1 August***	***Excessive % after initial intervention***	***Excessive % after follow-up intervention***
4B	3	12	22.2%	25.0%
4C	3	13	26.9%	23.1%
4G	2	13	22.2%	15.4%
4I	3	13	18.5%	23.1%
4N	5	13	33.3%	38.5%
4O	3	13	25.9%	23.1%
4R	5	12	36.4%	41.7%
Mean excessive emission % for high frequency emitters			***22.8%***	***27.1%[k]***
Overall mean excessive emission frequency			***16.0%***	***11.4%[l]***

As can be seen from the observations of smoke emissions from the houses in the Control group, the warmer weather in August 2015 resulted in a lower overall frequency of wood heater use, and consequently fewer excessive emissions, especially in the lower emitting households. The mean excessive emission frequency for this section of the Control was 1.4%[j]. Some of the regular high emitters also stopped using their fires with the onset of warmer overnight temperatures, but most of the very high emitters continued to keep their fires going, and continued to regularly emit excessive smoke. The mean excessive emission frequency for the regular high emitters in the Control group after 1 August 2015 was 27.1%[k]. This analysis supports an observation made during the testing of the *SmokeTrak* system in 2013, as noted earlier in this report – "*… it appears that many of the highest smoke emitters operate their fires for longer periods than most wood burning households, some even burning their fires on quite warm days.*"

Analysis of smoke observations from Condition 1 and 2 households after the follow-up intervention



Due to the lower number of observations made after the follow-up intervention, for analysis purposes we have combined the results for the Condition 1 and Condition 2 households who responded positively to the intervention program. A t-test on the means of both groups showed that there was no significant difference between the emission frequency of these two groups (t-stat = -0.2, t-critical two tail = 2.1).

Condition 1 & 2 Households – Combined Intervention Program Effective (<10% excessive)				
House Code	***Excessive***	***Observations***	***Excessive emission % after initial intervention***	***Excessive emission % after follow-up intervention***
1A	0	12	0.0%	0.0%
1B	1	12	7.7%	8.3%
1C	0	12	3.7%	0.0%
1D	0	13	0.0%	0.0%
1F	0	13	0.0%	0.0%
1H	0	13	4.0%	0.0%
1I	1	12	8.3%	8.3%
1J	0	13	0.0%	0.0%
1G*	1	12	25.9%	8.3%
2A	0	12	0.0%	0.0%
2C	0	12	0.0%	0.0%
2D	1	13	4.0%	7.7%
2E	1	13	0.0%	7.7%
2G	1	12	3.7%	8.3%
2I	0	12	7.4%	0.0%
2B	0	13	14.8%	0.0%
2F	0	13	13.6%	0.0%
2H*	1	13	18.5%	7.7%
2J*	0	12	29.6%	0.0%
Mean Excessive Emission frequency			***7.4%***	***3.0%[(m)]***

* Household received additional intervention follow-up letter.

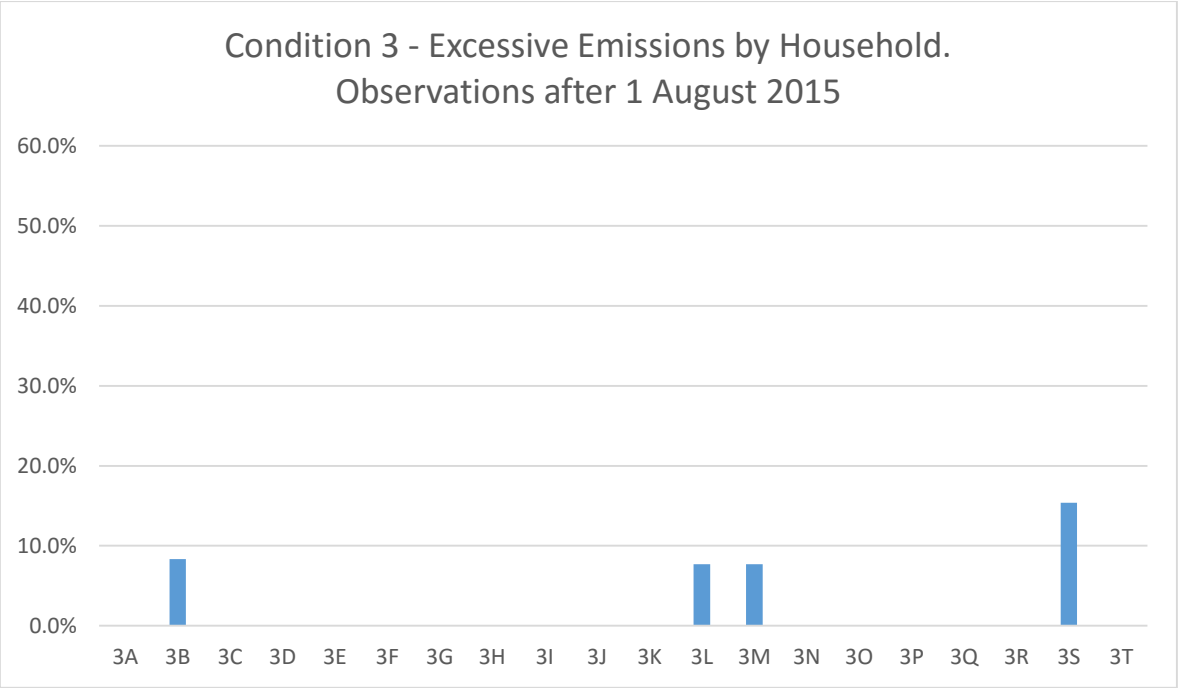
Condition 1 & 2 Households – Combined Intervention Program Not Effective				
House Code	***Excessive***	***Observations***	***Excessive emission % after initial intervention***	***Excessive emission % after follow-up intervention***
1G*	3	13	55.6%	23.1%[(n)]

* Household received additional intervention follow-up letter.

One of the two households in Condition 1 that was still emitting regularly after the initial "Enhanced Flue Clean" intervention stopped emitting immediately after receiving the follow-up intervention letter. From this group, only one household continued to emit excessively. Both of the households in Condition 2 that were sent the follow-up letter corrected their operating behaviour to stop emitting excessively.

The mean excessive emission frequency (after 1 August 2015) for all of the households in the groups who had responded positively to the face-to-face "Flue Clean" intervention, including the three households who stopped emitting after the follow-up letter was 3.0%[(m)]. This was compared to the overall Control group mean excessive emission frequency for the same period which was 11.4%[(l)]. A t test showed that the difference between the means of the two groups was significant (t Stat = 2.5, t critical two tail = 2.0).

Analysis of smoke observations from Condition 3 households after the follow-up intervention



One of the high frequency emitting households in this group installed a new flue, and presumably a new wood heater, during period of observations in 2015, which considerably reduced their emissions. The extent to which this particular household was motivated to modernise their heater as a consequence of the 2014 intervention letter is not known. Five other households in this group who were previously high emitters, appeared to reduce their emissions during the post-1 August observations even though they were not sent a follow-up letter. It is more likely that this was a consequence of less frequent heater use, due to the onset of warmer weather during August, than any residual effect of the 2014 intervention. Therefore, the post-1 August emissions from these six households were not included in the analysis of the effectiveness of the follow-up intervention for Condition 3 households. We note that a similar reduction in excessive emission frequency was observed in the Control group for this period of observations, which is an indication that weather conditions during August caused a reduction in wood heater use.

Condition 3 Households – Flue Clean Letter Plus Follow-Up Effective (<10 % excessive)				
House Code	***Excessive***	***Observations***	***Excessive emission % after initial intervention***	***Excessive emission % after follow-up intervention***
3B	1	12	7.4%	8.3%
3C	0	13	0.0%	0.0%
3D	0	13	0.0%	0.0%
3F	0	13	3.7%	0.0%
3I	0	13	3.7%	0.0%
3J	0	13	3.7%	0.0%
3K	0	13	3.7%	0.0%
3O	0	13	7.4%	0.0%
3Q	0	12	0.0%	0.0%
3T	0	12	7.7%	0.0%
3N*	0	13	37.5%	0.0%
3P*	0	13	26.9%	0.0%
3R*	0	13	33.3%	0.0%
Mean Excessive Emissions			***10.4%***	***0.6%[o]***

* Household received additional intervention follow-up letter.

Condition 3 Households – Flue Clean Letter Plus Follow-Up Not Effective (> 10% excessive)				
House Code	***Excessive***	***Observations***	***Excessive emission % after initial intervention***	***Excessive emission % after follow-up intervention***
3S*	2	13	18.5%	15.4%

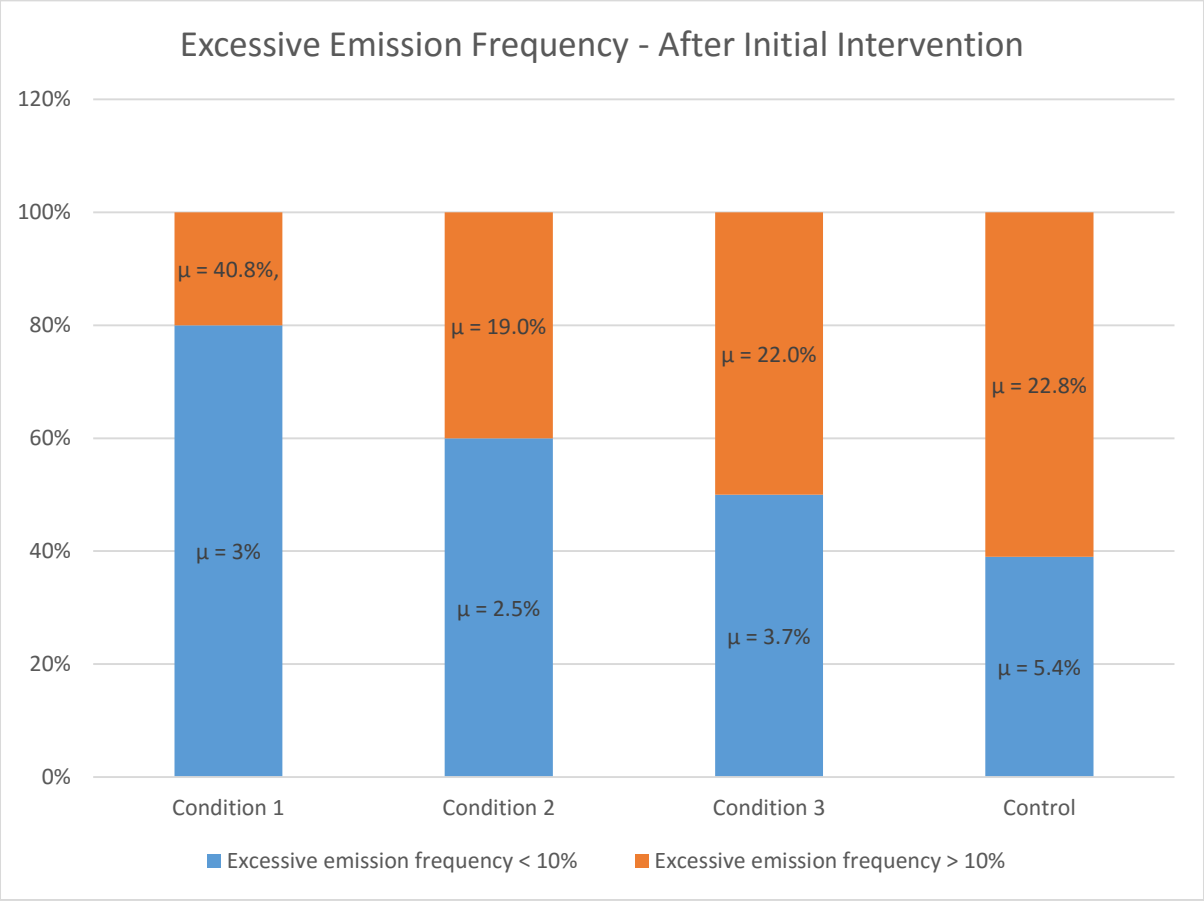
* Household received additional intervention follow-up letter.

Three of the four households in Condition 3 that were sent the follow-up intervention letter corrected their operating behaviour immediately and stopped their excessive emissions. The mean excessive emission frequency after 1 August 2015 for all of the remaining households in this group, including those who received the follow-up letter was 0.6%[(o)]. This mean was compared to the overall Control group mean excessive emission frequency of 11.4%[(l)]. A t-test showed that the difference between the two means was significant (t Stat = 3.0, t-critical = 2.0). We conclude therefore that the combined program of interventions was 93% effective for this group.

Discussion – Post-Intervention Observations

At the completion of the observation period of smoke emissions from households in the three groups that received one or more interventions, we were able to conclude that the combined program of targeted interventions was highly effective.

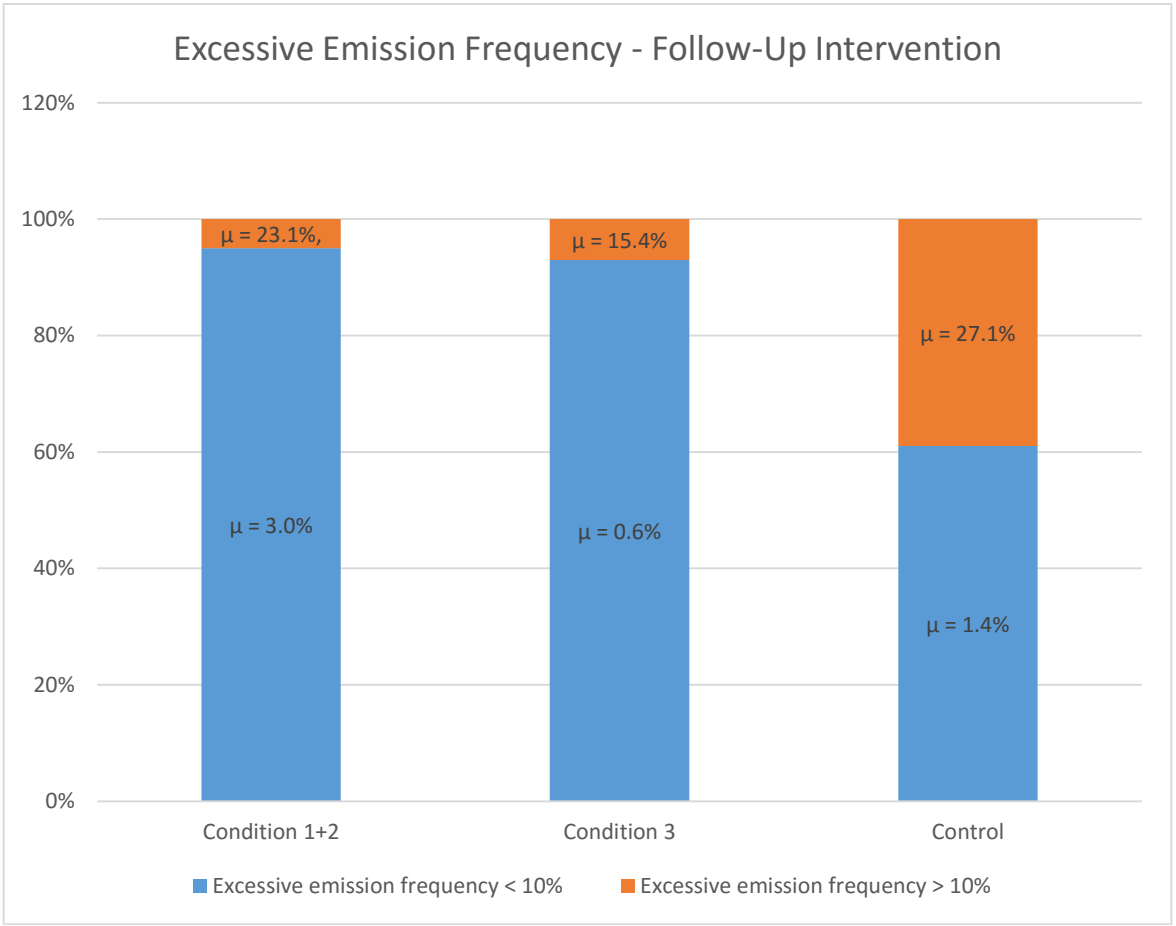
The observations made after the initial interventions were conducted indicated that the majority of households stopped emitting excessively immediately after they received the intervention. Both of the face-to-face interventions were especially effective. In the group who declined the offer of free flue clean, one half appeared to stop emitting however, it is uncertain how much of this apparent change was motivated by the letter and how much was simply the natural variation in heater use that was also observed in the Control group. In all groups who received an intervention, a small number of households continued to emit excessively.



The follow-up intervention, which contained a direct instruction by Council to stop excessive smoke emissions and advised households of the possibility that they could be prosecuted, appeared to provide sufficient motivation for most of the recalcitrant emitters to change their operating practice.

Feedback from the householders who contacted the council after receiving the follow-up intervention letter indicated that these people had initially refused to believe that they were emitting smoke. This was the case for households in all 3 experimental Conditions. Some of these householders were still denying that they were at fault even after receiving the follow-up letter, claiming that it was their neighbour's chimney that was smoking or that the amount of smoke they emitted was not excessive and was similar to other wood heaters in their vicinity.

Because the 'additional' intervention that was carried out on these recalcitrant emitters occurred fairly late in the season, only a limited number of observations were possible. Also an unseasonable warm spell in late August meant that very few wood heaters were operating which limited the ability to fully assess the effectiveness of the second round of interventions. However, the results we obtained indicate that the targeting of persistent emitters with a more forceful motivation to change their behaviour appears to have been highly successful.



SUMMARY OF POST INTERVENTION OBSERVATION FINDINGS							
		Condition 1 & 2		Condition 3		Control	
		Number	Mean	Number	Mean	Number	Mean
Initial Intervention	High emitters	6	26.3%	10	22.0%	11	22.8%
	Low emitters	14	3.7%	10	3.7%	7	5.4%
Follow-up Intervention	High emitters	1	23.1%	1	15.4%	7	27.1%
	Low emitters	19	3.0%	13	0.6%	11	1.4%

Of the twenty households that received the "flue clean" targeted face-to-face intervention during this study, (Conditions 1 and 2) only one household could be considered to be a regular high emitter at the end of the observation period. Even the free flue clean offer letter (Condition 3), which notified the householder that they were emitting unacceptable amounts of smoke, appeared to be reasonably successful, especially when the initial message was reinforced by a follow-up letter from Council that contained a direct instruction for them to reduce their smoke emissions.

We found that the Condition 3 "free flue clean offer" to be less effective than the "card in the letterbox" method that was used during the Launceston Targeted Education project and also during the EPA Tasmania *Burn Brighter* programs. The effect of this type of intervention is to alert householders to the fact that they are emitting excessive smoke, and also that an authority is monitoring their smoke emissions. In the Launceston program, and during the first year of the *Burn Brighter* program, approximately 80% of households stopped emitting excessively after receiving the notification. The effectiveness of this method was studied more thoroughly by EPA Tasmania during the second year of the *Burn Brighter* program that was carried out in Geeveston and Hadspen. This analysis cast some doubt about the efficacy of this intervention method. We found that, at most, 50% of the households who received this type of intervention may have reacted positively and taken steps to reduce their emissions. It is possible that the intentionally "friendly" wording of the initial "free flue clean offer" was not taken seriously by some householders, and therefore failed to have as much impact as the slightly more official "card in the letterbox" method used in the Tasmanian programs. On the positive side, we are not aware of any overreaction, or hostility toward the Council by recipients of the free flue clean offer, which was a reported limitation to the programs that were run in Launceston and Hobart.

One of the clear findings from this project is that almost all wood heater owners are open to changing their operating practices, so that they avoid creating excessive smoke emissions, once they accept that they are not operating (or maintaining) their wood heaters correctly. As has been demonstrated by this project, some householders simply need to be effectively alerted to the fact that they are creating a smoke nuisance to bring about a change in their practices.

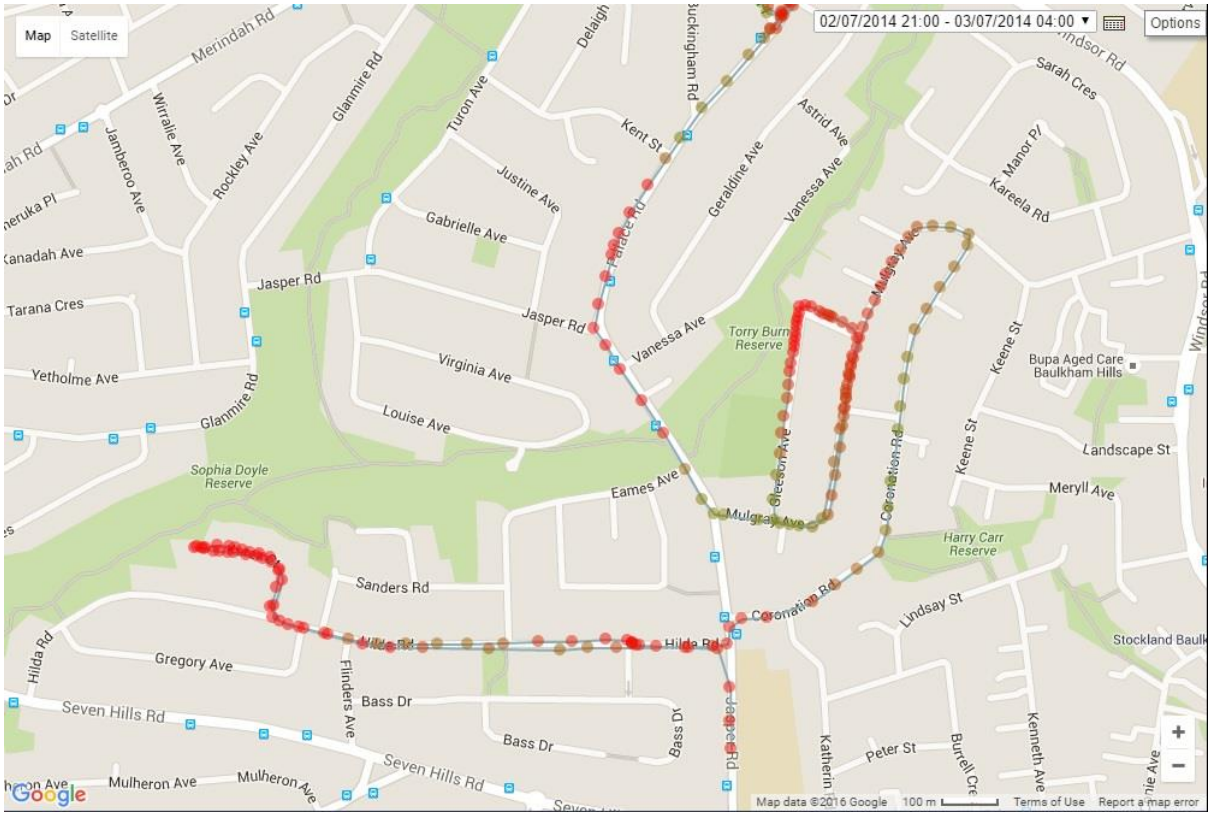
To effect a change their wood heater operating behaviour, many householders clearly need slightly more motivation than a letter notifying them that they are emitting unacceptable amounts of smoke. The personal, non-threatening, expert advice provided by the wood heater service professionals during this project, appears to be a highly effective way to deliver the necessary extra motivation to these householders.

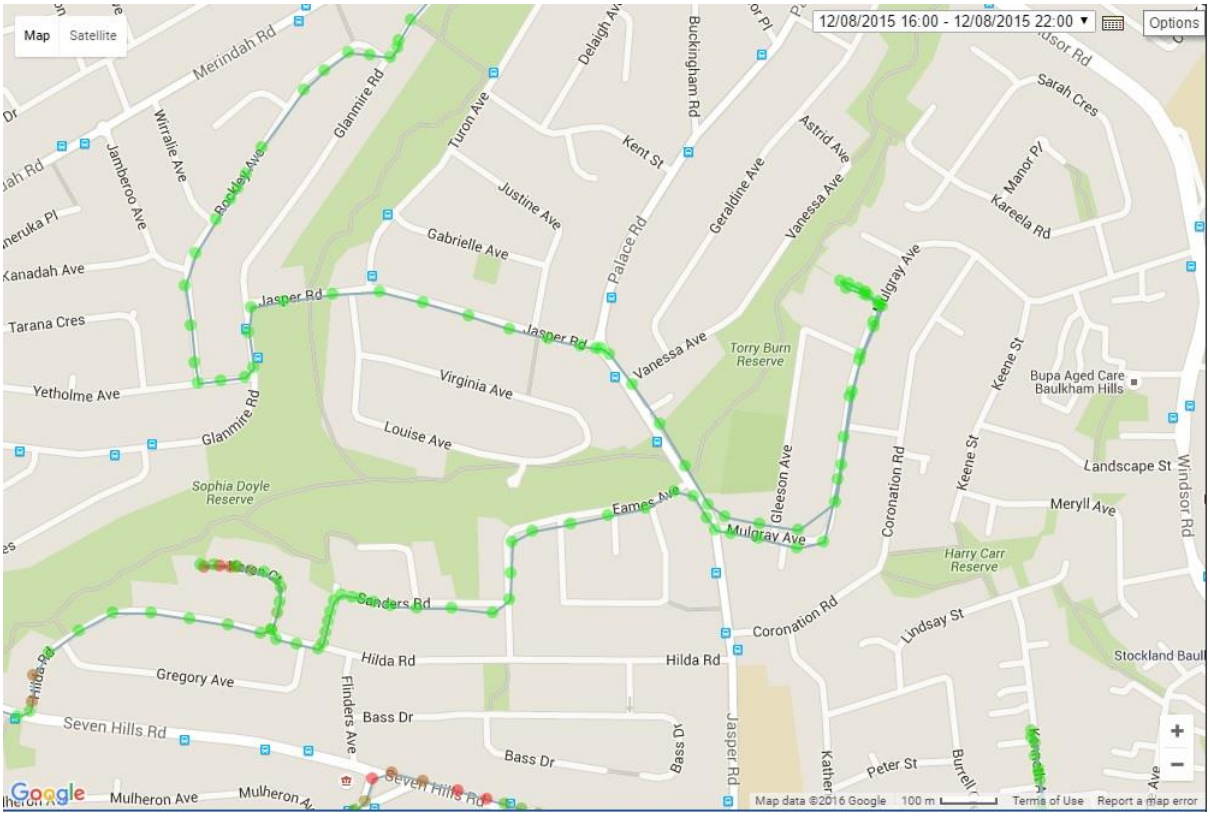
For the small number of householders who are in serious self-denial about the unacceptable nature of their smoke emissions, a more direct and forceful approach is necessary to convince them that they need to correct their operating practice or rectify problems with their wood heater. The success of the follow-up notification letter issued by Council during this project shows that alerting householder to the possibility that they may be prosecuted is usually sufficient to bring about a change in behaviour. It is likely that many of these recalcitrant householders still do not believe that they are operating their heaters incorrectly, but most will react appropriately in order to avoid further action being taken against them by the Council. For this type of householder, it is likely that a photograph of the excessive smoke being emitted by the flue on their house would help to convince them that they are responsible for the excessive smoke, and that the smoke is not coming from a neighbour's flue.

Local Area Winter Smoke Reduction

During the conduct of the surveys, both before and after the interventions, particular note was taken of the amount of wood smoke that was observed regularly in certain areas.

The *SmokeTrak* images below show an area of Baulkham Hills that has some sporting fields that were in use at night during week days. As noted elsewhere in this report, wood smoke emissions vary considerably due to the prevailing weather conditions and also the *Smoke Trak* readings are dependent on wind direction. Without having consistent time series data available for any one area it is not possible to be conclusive about any reduction in ambient wood smoke levels, however the below *SmokeTrak* images were chosen to show survey data under similar weather conditions. The minimum temperatures at the times of the measurements displayed in the images below were similar (3.2 & 4.9^{0}C) and there was minimal wind. The *SmokeTrak* readings, as well as the floodlights at the Torry Burn Reserve sporting fields, showed that there was a marked reduction in the amount of smoke that was hanging in the air over these sporting fields from one year to the next. It is likely that this improvement was a direct consequence of the better wood heater operation by one of the very high emitting households in the study who received the enhanced face-to-face advice (Condition 1) on the correct method of operating a wood fire.

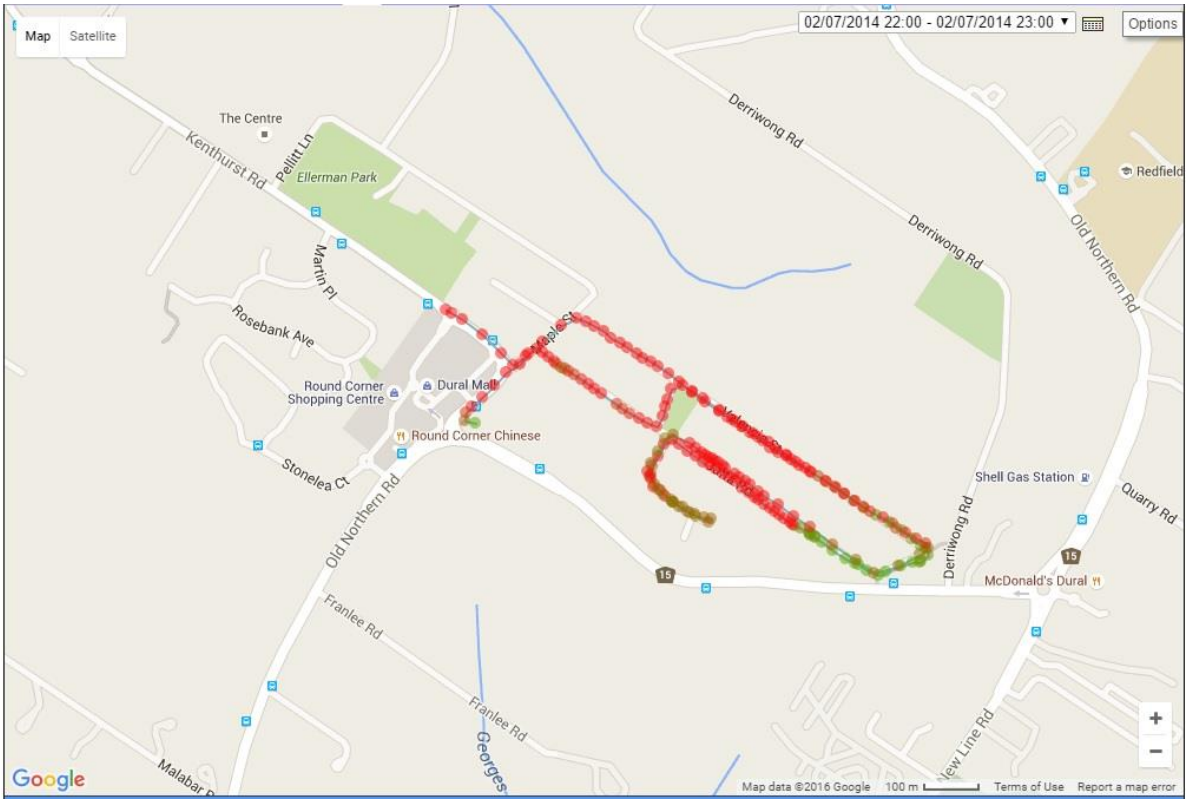




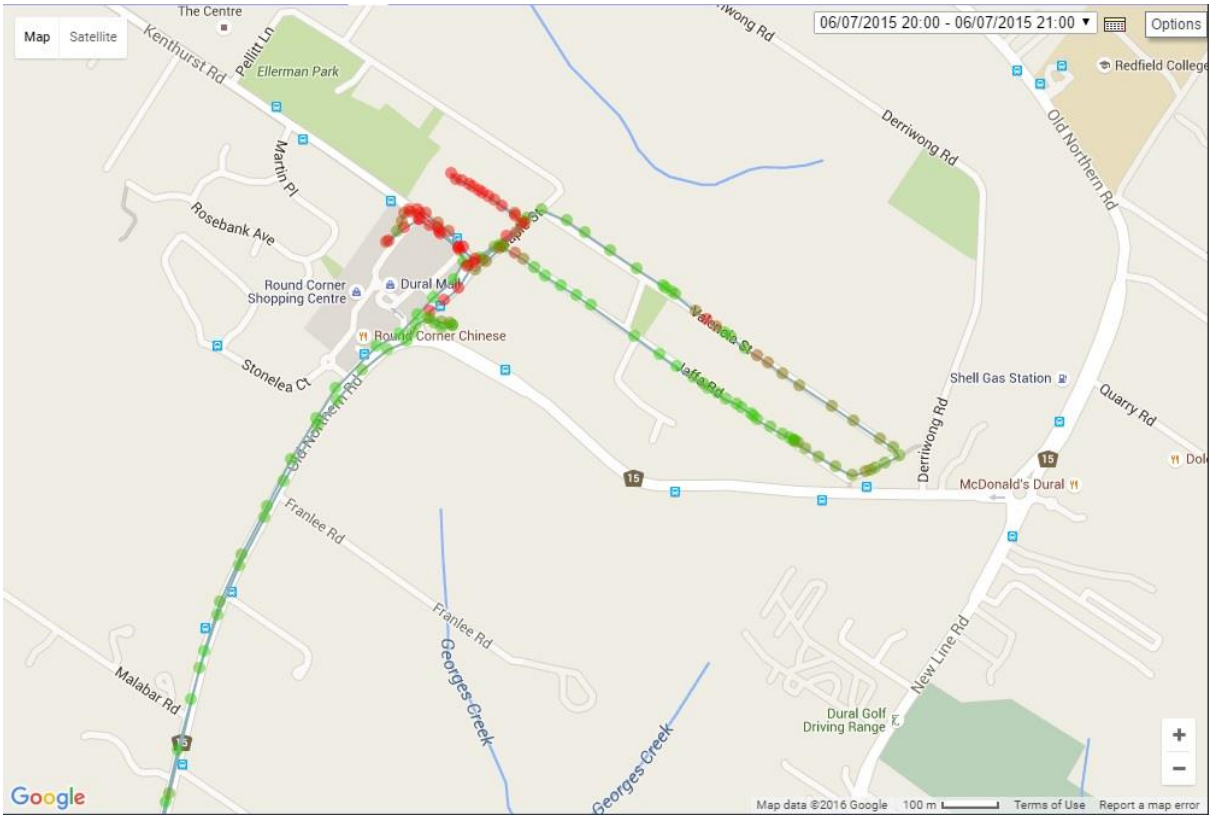
This type of improvement in local area air quality was noticeable in several other areas of The Hills Shire that had fewer smoky wood heaters as a result of the interventions carried out during this project. It is reasonable to assume that a prolonged program of targeted intervention in a smaller geographical area would result in a very substantial reduction in local area winter wood smoke pollution.

The following *SmokeTrak* images show the typical reduction in ambient wood smoke in an area of Dural which had several households that reacted positively to the interventions delivered during the project.

The first image shows the widespread heavy smoke that covered most of this residential area in July 2014.



The second image below shows *SmokeTrak* readings 12 months later. The high readings that can be seen near the Round Corner Shopping centre were from smoke emitted by two of the households that were in the Control group of the study. The high smoke reading that can be seen about the middle of Valencia St was coming from a house with an open fire that was not a part of this project.



Once again, the temperature and weather conditions at the time of both images were similar. On 2 July 2014 the overnight minimum was 3.2 degrees with little wind and on 6 July 2015 the overnight minimum was 1.5 degrees with calm wind. Without consistent time series data from a fixed station that showed $PM_{2.5}$ levels and the weather conditions it is not possible to positively attribute this apparent improvement in air quality to the reduction in excessively smoking flues, but this would appear to be the case.

SUMMARY

The results of the targeted interventions carried out in this study clearly demonstrate that high wood smoke emitting households can be successfully motivated to change their behaviour, or in some other way improve their wood burning practice to effectively eliminate the creation of nuisance wood smoke.

Feedback and responses from the householders who received intervention in this study show that the main motivation for them changing their wood heater practice, or improving their wood burning installation, was their desire to conform to community acceptable standards of behaviour. As indicated by the Launceston pilot program[26], most wood burning households want to be responsible community citizens and therefore, by simply alerting households to the fact that they are emitting excessive smoke, some will take action to stop emitting. In this study potentially up to 50% of the contacted households may have taken steps to remedy the problem without any further intervention or contact from the council.

From the sample of persistent smoke emitting households that were sent the follow-up letter of demand by Council, only two households continued to emit excessive smoke. One householder stubbornly maintained that his fire was not emitting unacceptable or excessive smoke, certainly no more smoke than other wood fires in the immediate neighbourhood. This householder said that he had contacted all of his neighbours to ask if his fire was creating a smoke nuisance for them, to which they all replied that it wasn't. Even when he was shown *Smoke Tra*k mapping of the smoke dispersion from his wood fire he was unconvinced, believing that the smoke could have come from other nearby fires. This was a reasonably common response from the householders who received the additional intervention. Many maintained that the observed smoke was coming from a neighbour's fireplace.

Although not trialled during this project, it is likely that a photograph showing excessive smoke being emitted from the chimney of the offending household would counteract this denial of responsibility. The photo would need to be taken during daylight hours, either early morning or late afternoon, which should be achievable because all of the highest emitters in this study regularly operated their heaters during daylight hours. A copy of the photograph could be attached to the follow-up letter for these recalcitrant emitters.

An improvement in winter air quality in the areas of The Hills Shire, where households in this study had substantially reduced their smoke emissions between the 2013/14 and the 2015 surveys, was obvious to the team conducting the field assessments. Some areas that were almost always smoke affected during still cold evenings in 2013 and 2014 were comparatively free of smoke during most of the 2015 survey period. This apparent difference in local area air quality, as a result of correcting the operation of a single high emitting flue in some instances, was an unexpected and surprising outcome.

This project confirmed that specifically targeting the highest emitting households is a highly effective way to achieve a substantial improvement in local area winter air quality.

[26] Ling, B. (2004). Targeted Education of Woodheater Users in Launceston. *Environmental Health Vol. 4 No. 4 2004*.

CONCLUSION

The results of the post-intervention monitoring (Phase 3) surveys showed that, compared to a Control, the directly targeted intervention program carried out during this project was highly effective in reducing the frequency of high smoke emissions.

- The households that received the "enhanced" flue clean intervention (Condition 1) showed considerable improvement, with eight of the ten households not emitting excessive amounts of smoke following the initial intervention. After the follow-up letter, only one household continued to emit excessively. This household would require further motivation to force a change in their wood fire operating behaviour.

- The households that received the free flue clean without the additional advice (Condition 2) also showed a marked improvement in their smoke emissions. Sixty percent the houses did not emit excessive smoke after the initial intervention. Both high emitting households in this group that were sent a follow-up letter stopped emitting immediately after receiving the letter.

- The households that received the free flue clean offer from council but did not accept the offer also showed a moderate reduction in their smoke emissions. Fifty percent of these (Condition 3) households stopped emitting excessively after receiving the flue clean offer however, some of this apparent reduction may have been due to variations in the weather conditions. Of the four households in this group who received the follow-up notification letter, three immediately ceased emitting. The one household that continued to emit excessively would require further stimulus to bring about a change in their operating practice.

- The Control group showed no significant change in their smoke emitting behaviour over the duration of this program, other than the expected variation in wood heater emissions due to changes in the weather.

In summary the face-to-face flue clean intervention program trialled during this program achieved a significant reduction in excessive smoke emissions for 95% of high emitting households. The program indicated that notifying householders about their excessive emissions can also be reasonably effective, especially when the initial notification is supported by a more forceful follow-up directive to households that continue to emit excessive smoke.

The proven success of the face-to face interventions tested during this project provides sound evidence that targeted education, combined with a notification of the potential for prosecution, will achieve a substantial improvement in the wood fire operating practices of high smoke emitting households

RECOMMENDED SMOKE CONTROL STRATEGY FOR COUNCILS

This project had two main aims; develop an efficient method of identifying problem wood smoke emitters, and design and implement an effective targeted education intervention strategy for high smoke emitting households

After three years of field use, the *SmokeTrack* system has been proven to be a simple and effective way of locating problem wood smoke emissions. The system has also shown that it could be a highly effective way for councils to prioritise localities within their jurisdictions that are in most need of action to reduce levels of winter wood smoke.

The use of the *SmokeTrak* system across the large Hills Shire area has shown that the topography and the demographic profile of suburbs has a major influence on wood smoke pollution. Whenever the weather conditions were conducive to allowing smoke from domestic fires to linger and accumulate, instead of being dispersed by wind, the same localities within suburbs were repeatedly impacted by heavy smoke. Under the same metrological conditions, other localities were quite unaffected, either because there were few houses that had operating wood heaters, or because the topography assisted rapid dispersion of smoke.

This indicates that the initial step in the conduct of any local government wood smoke reduction program would be to use the *SmokeTrak* system to "map" wood smoke concentrations across the entire council area. This mapping would need to take place on reasonably calm, cold winter nights when most wood fires are most likely to be in use and their smoke is not blown away. The resultant Pervasive Telemetry map image could then be used to identify smaller areas that can be prioritised for detailed surveying to enable the identification of individual, high emitting households.

When the highest emitting households in an area have been identified, this project has demonstrated that a staged, targeted intervention program can be effectively used to bring about a reduction in the smoke emissions from these households. The results of this project indicate that the most efficient way to achieve a change in behaviour is to initially make contact with the householder through a "friendly" letter informing them that they are emitting excessive smoke. If, as shown by repeated surveys, the smoke emitting behaviour from the targeted household does not change, council could offer a free flue clean paid by council (cost approximately $200 per household), or alternatively recommend that a flue clean be carried out by a wood heater service provider. The service provider carrying out inspection of the heater or fireplace should advise the householder (and Council) of any repairs and/or modifications that are required to improve the efficiency of the heater, including the fuel used and the correct method for lighting and operating the heater or open fire.

If further repeat surveys show that the targeted household has not responded positively to these initial interventions, a more forceful letter demanding the householder stop emitting should be issued with an invitation for the householder to contact Council for assistance if required. As noted above, it may be beneficial to include photographs showing the smoke being emitted from the household's chimney with the "forceful" letter.

As a last resort Councils can instigate punitive action under the relevant state environment legislation, to force a change in behaviour of the smoke emitting householder.

As demonstrated by this study, as well as the Launceston pilot program and the subsequent "*Burn Brighter*" programs being run by EPA Tasmania, most high-emitting households will change their heater operating practices once they accept that they are emitting abnormal or socially unacceptable amounts of smoke. It is expected that punitive action will only be required on very rare occasions, when a householder is stubbornly defiant.

In summary, the following steps are recommended as a way for local governments in Australia to address any concerns they may have about domestic wood smoke pollution within their jurisdictions:

1. Use the "*SmokeTrak*" system to 'map' wood smoke concentrations and prioritise localities that have the worst winter air quality.
2. Use a combination of the "*SmokeTrak*" readings and visual observation to identify households that regularly emit excessive smoke in the prioritised locality.
3. Contact local wood heater service professionals who are prepared to carry out in-house education and inspection where possible.
4. If necessary, request repairs or modifications be made to the high emitting wood heater or flue installation.
5. Monitor wood smoke emissions from the targeted households after intervention.
6. Where necessary, issue a letter demanding cessation of smoke emissions which raises the possibility of prosecution if the householder fails to respond.
7. Instigate proceedings against any recalcitrant emitters if required.
8. Use "*SmokeTrak*" to measure local area air quality improvement.

This suggested program is affordable because it can be carried out by a single staff member during the winter, wood burning season. Operation of the "*SmokeTrak*" system is relatively straight forward and does not require any special skills or training. A complete "*SmokeTrak*" unit can be purchased or hired from Kenelec Scientific (www.kenelec.com.au). To ensure confidential access to, and security of the survey data, it is preferable that organisations carrying out a smoke reduction program establish their own account with Pervasive Telemetry (www.pervasivetelemetry.com.au), although this can also be arranged through Kenelec Scientific.

This research project has established that any council, or other organisation wishing to conduct a wood smoke reduction or abatement program, can be confident in its success if the protocol outlined above is followed.

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