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GIS-BASED INCIDENT FORECASTING

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This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Abstract

The current population growth and urban expansion in Victoria, Australia is increasing the need for effective fire control through the planning and allocation of fire safety resources. This project assisted the Country Fire Authority (CFA) by modelling emergency incidents in Victoria, forecasting future incident patterns, and identifying high fire risk regions.. This task was accomplished by developing a prediction tool using Geographical Information Systems. In addition to assisting the CFA with fire suppression planning, this method may aid other institutions and communities by establishing a new standard for fire risk assessment.

Authorship

This report was prepared by Richard Fowler, Nathaniel Liefer, and Adam Norige. Each participated in the mathematical analyses, the field research, and the report that follows.

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Executive Summary

As city populations rise, their outward expansion causes people to inhabit the surrounding areas, increasing the responsibility of fire fighting agencies. In Victoria, Australia fire officials at the Country Fire Authority (CFA) are facing the same problem of expanding suburbs requiring extended fire protection. However, the extreme fire danger in the popular wild land-urban interface areas surrounding Melbourne, such as the Dandenong range east of the city, have restricted the development of new dwellings. This limitation, combined with the high development expenses in these interface regions, is attracting residential growth into nearby grasslands, creating population growth "corridors."

The appearance of these growth corridors in Victoria in recent years is increasing the Country Fire Authority's fire fighting responsibilities. This growing responsibility, coupled with the CFA's large jurisdiction, makes fire safety management and resource allocation vital to the efficiency and effectiveness of the CFA. Under impetus from a 1999 national standard for risk management, the CFA is developing a new method for standardising fire cover that stresses equitable emergency service provisions for all Victorians. In addition, the standard emphasizes proactive fire hazard avoidance to complement the existing fire response methods. Towards this end, a GIS-based incident forecasting tool will greatly assist the CFA in planning for fire safety.

Through research and statistical analyses, we compared the correlations of various demographics for Victoria to the emergency incidents the CFA responded to from 1999 to 2001. From this study, we found that dwelling statistics were the best indicator of emergency incidents and selected this relationship for modelling purposes. The resulting model was used to forecast future incident patterns across

Victoria based on residential development projections. These incident forecasts were analysed and compiled to produce risk projections. The projections forecasted a drastic increase in incidents in Melbourne's fringe suburbs. Several major growth corridors are expected to experience double or triple the number of yearly incidents by 2005, creating a significant increase in the CFA's work load.

The forecasts produced by our model are intended to assist the CFA's planning process by projecting emergency incident patterns. The model will not only assist the CFA with the allocation of available fire resources, but will also support requests for additional funding when available resources are not adequate for the incident projections. The model also provides the CFA with a potential means to evaluate their fire safety programs. Furthermore, an analysis of the incident trends will provide a better understanding of fires in Victoria and the risks associated with them.

To provide groundwork for improving on the model produced by this project and develop incident forecasting models that are highly effective and robust, different modelling techniques such as system dynamics were examined. The ability for future models to adapt to changes in the Victorian environment and society will be a pivotal issue for continued prediction accuracy. A model's ability to adapt is of principal importance because it dictates the believability and the life span of future models.

The completion of this project resulted in a GIS-based incident forecasting tool that has the potential to increase the efficiency of the CFA by reducing costs and increasing the effectiveness of their fire management programs. The products of this project have the potential to impact fire control throughout the world by setting a new standard for fire suppression planning.

Chapter 1. Introduction

Throughout the world, urban populations are increasing. Because these escalating populations stress the physical limits of the world's cities, urban planners must devise new methods to combat this outward expansion. This outward expansion of cities into the surrounding areas is more generally known as urban sprawl. Urban sprawl creates new problems, which are raising concerns to many urban planning specialists (Country Fire Authority, 2001b). Similar to the rest of the world's major cities, Melbourne, Australia is suffering from the implications of urban sprawl. In Victoria, the greatest population growth is occurring in the areas surrounding Melbourne and in other regional cities (Victoria Department of Infrastructure, 2000a). The Country Fire Authority (CFA) for the state of Victoria is experiencing similar problems of urban expansion. As more people move into the areas surrounding Melbourne, the responsibilities of the CFA increase. The CFA's growing accountability makes fire awareness and preparedness a current issue, thus creating a demand for more advanced fire prediction tools. In response to a state-wide government policy, the CFA is broadening from a reactive fire response approach to include a proactive fire deterrence system. In order to become a proactive organization, the CFA requires an increased understanding of fire hazards through a standardized risk analysis procedure.

The goal of this project is to develop statistical-based methods of fire incident prediction to assist the CFA with the future planning for fire suppression resources through risk analysis. We believe that these methods will provide the CFA with new information to base decisions on the planning of future resources. The outcomes of this project will allow the CFA to assess the fire risk in growth corridors and determine the adequacy of their protection coverage in these areas.

Completion of this project should produce the following: an analysis of the relationships between fire statistics and existing GIS databases, a methodology for the prediction of incident occurrences, an analysis of the current fire threat in Victoria, and documentation detailing the work accomplished. The examination of fire trends should lead to the selection of appropriate statistical techniques, followed by the construction of a model that relates past fires to social, economic, and geographic contexts. This analysis should produce a process for identifying areas of high fire risk, an understanding of local fire danger, and recommendations for alleviating the threat.

This project will result in the development of a GIS-based incident prediction model. The products of this model will yield recommendations for improvements in the CFA’s policies regarding fire protection. This project aims to quantify the increasing fire hazard in Victoria, assisting the CFA in planning for future fire safety.

Chapter 2. Literature Review

Urban Sprawl

Because increased populations stress the physical limits of the world's cities, urban planners are left with two fundamental choices. Urban areas can either grow upward in the construction of taller buildings to support more people per unit area, or they can expand outward, increasing the population on the outskirts of cities. In most parts of the world, including Victoria, cities are choosing to expand outward (Victoria Department of Infrastructure, 2000b). The outward expansion of cities into the surrounding areas is known as urban sprawl. This outward expansion is creating many new problems to both the people moving out of the cities and to the governments in charge of these expanding areas. One problem in particular is the increased fire risk to homes along the urban-wild land interface coupled with decreased fire prevention coverage (Federal Emergency Management Agency, 1992). Environmental impacts of urban expansion have prompted an investigation into the root causes of sprawl. The investigation of the negative impacts of urban sprawl reveal that the automobile, the structuring of urban planning policy, and the ideals held by the general population increase urban expansion and increases fire risk.

Urban Sprawl and Environmental Problems

Although there are many problems associated with urban sprawl, the major problematic areas tend to be environmental in nature. Environmental problems such as diminished wild lands, increased pollution, and heightened fire threat are direct results from urban sprawl (Sheehan, 2001). As people venture out of the cities in search for new places to call home, they often invade uninhabited forests or start to reclaim farmlands for urban development. Air pollution is also a major product of urban sprawl because of an increased reliance upon the automobile, which is a major contributor to air pollution. When people choose to drive personal automobiles instead of using public transportation systems the air quality is lowered as more fossil fuels are consumed (Sheehan, 2001). In addition to the consumption of land and the degradation of air quality, urban sprawl also increases the risk of major fire damages to communities on the urban-wild land interface. For example, Pyne (1991) explained that homes near the mountainous regions of Australia, such as the Dandenongs on the outskirts of Melbourne, were high-risk areas for the threat of fire damage. This area was deemed as a high fire risk area because of the climate conditions and the proximity of homes to natural fuel sources. Pyne continues to cite some relatively small fires, which occurred in January of 1962 in the Dandenongs and destroyed over 454 homes. The recent fires in Sydney also exemplify the perils of developing homes in the urban-wild land interface. The Sydney fires of 2001 consumed more than 570,000 hectares (1.2 million acres) of land while destroying over 170 properties (Arrests mount as stunned Sydney burns, 2002).

Automobile as a Cause of Sprawl

One of the strongest driving forces behind urban sprawl is the development a lifestyle centered around the automobile. Sheehan (2001) explains that for years, automobile manufactures have spent large sums of money on advertising to promote the idea of a car-centered lifestyle. Statistics on automobile users prove that the automobile marketing campaigns were successful. In Sydney alone, 69.3 percent of people who commute to work use private vehicles, while only 25.2 percent utilize public transit as a means to get to work. In addition, Australia ranks second to the U.S. in reliance upon cars, while densely populated Europe and Asia depend more upon public transit (Sheehan, 2001). As a result of increased private transportation, governments are authorizing the construction of more highways, which in turn, increases the lure of suburban living, encouraging sprawl.

If the automobile remains the focal point of many lifestyles, fire risk on the urban-wild land interface and other environmental problems will increase. Even the attempt to implement widespread public transportation systems will not always adequately reduce the dependence upon cars. Foldvary (2001) states that the introduction of low-density settlings on the outskirts of many urban areas makes widespread public transit almost impossible due to economic reasons. Secondly, Gordon and Richardson's (2000) research shows that people prefer the use of cars because of convenience and because they are able to complete door to door travel. With modern society pushing the rapid expansion of roadways over rail systems, giving drivers new freedoms to settle where they please, it is inevitable that urban sprawl will continue to escalate.

Government Policy Encouraging Sprawl

Government policy also contributes greatly towards urban sprawl. The taxing and zoning policies in suburban areas provoke the urbanization of the fringe areas around major cities (Sheehan, 2001). Foldvary (2001) explains that public works projects increase land values and encourage expansion into undeveloped areas. When a local government provides public works, such as water, sewer, and fire services to the members of its community, the land values in the community must increase in order to cover the costs for the government's public works spending. These increased land values turn land developers away from areas on the fringes of the city to areas further away, in search of less expensive land. This process propels urban sprawl even further away from the cities (Foldvary, 2001). In conjunction with the search for lower land prices, many people living in metropolitan areas look toward the suburbs for improved public services and lower taxes (Guhathakurta and Wichert, 1998). The zoning policies established outside of the cities encourage urban sprawl because zoning laws are established to keep residential, commercial, and industrial areas separate (Minerd, 2000). In addition to the contribution of government policy to urban sprawl, the underlying psyche of the population promotes polices that contribute to sprawl.

Australian Identity and Urban Sprawl

The values held by the general population contribute a significant amount to the magnitude of urban sprawl. The desire to move out of cities into the surrounding fringe areas often exceeds the cost of long commutes and fuels urban expansion. People in many regions do not want to live in the cities, but prefer to visit the cities at their convenience, experience the cultural benefits and career opportunities, and then return to their homes away from the dense congestion (Sheehan, 2000). For example, Gordon and Richardson (2000) claim that in America, a culture seemingly similar to Australia's, about 80 percent of households would prefer to live in single-family homes, rather than inner city apartment buildings or townhouses. This claim suggests that people naturally want have their own space to live and not feel confined by the constraints of a crowded city.

In Australia, there are additional fundamental motivations for wanting to live outside of the cities. In 1991, Pyne claimed that most Australians were embarrassed by the European influences because they felt that they should live in harmony with the bush rather than in densely structured cities. For Australians, avoiding settlement in urban centres is a way of separating themselves from the European influence; it is an expression of their identity. In addition, Australians perceive land with greater isolation and looser settlement patterns as having increased value (Pyne, 1991).

Due to the Australian people's desire to push further into the bush, the environmental impacts of expansion must be reconciled, including fires on the urban-wild land interface. Pyne (1991) notes that the merging of significant populations with the bush creates an enormous fire threat that worries fire officials. However, for the Australians, living in the bush is a national identity and they are willing to seek other solutions to combat the ramifications of urban sprawl, such as improving their public fire control systems.

Case Study: Fire Danger on the Wild Land-Urban Interface

Fire danger is always present on the wild land-urban interface. As more people construct homes away from the cities and deeper into wooded areas, they are placing themselves near enormous sources of fuel. This proximity to natural fuel sources increases the occurrence of fire. The East Bay Hills fire on the border of Oakland and Berkeley California is a prime example of the immense fire threat on the wild land-urban interface. An in depth analysis of this fire, conducted by J. Gordon Routley for the United States Fire Administration, discovered that the combination of the regional climate, the blending of urban areas in wild land regions, and reduced fire suppression planning contributed greatly to the 1991 East Bay Hills Fire disaster.

The East Bay Hills ridge rises about 1,300 feet above sea level and runs parallel to the California coastline. Much of the suburban population for Oakland and Berkley reside in the East Bay Hills area. On October 19, 1991 a large fire broke out in the East Bay Hills and completely devastated much of the area. The fire was so intense that it could not be contained by fire services until October 22, 1991. Claiming twenty-five lives and over 3,000 buildings and resulting in over $1 billion U.S. in damages (Routley, 1992), this fire proved that the pleasures of living in a wild land setting come with a great risk. A complete understanding of the factors leading up to such a fire is the only way to reduce this risk.

The coastal areas of southern California are extremely susceptible to fire due to the dominant weather conditions consisting of periodic droughts, occasional winter freezes, and strong winds (Routley, 1992). In addition, the area's vegetation, consisting of eucalyptus trees imported from Australia and Monterey pine trees native to California, is highly flammable and burns very rapidly (Routley, 1992). Between 1986 and 1991, much of California was experiencing extended periods without rain. These drought conditions killed off large amounts of brush and eucalyptus trees. In December of 1990, the temperatures became low enough that freezing occurred and even more trees and light brush died, only to accumulate on forest floors, serving as the perfect fuel for fire. Reaching velocities of 35 to 70 miles per hour, the winds in this region contributed greatly to this fire (Routley, 1992). These strong winds have the potential to spread fires extremely large distances, completely overwhelming any attempts of suppression.

The areas of the East Bay Hills region are a prime example of a wild land-urban interface. During the 1960s, small roads were constructed throughout the East Bay hills, allowing for the development of homes with values ranging from 250,000 to millions of dollars (Routley 1992). People rushed to construct homes in the East Bay Hills because the elevation gave them a great view of the cities below and they liked the serenity of living in densely wooded areas. People building in these areas did not account for the threat of fire, evident through their use of wood shingle roofs and the lack of fire regulations for buildings. In most cases natural fuels such as trees and light brush surrounded the homes. This lack of planning and understanding of the natural fire threat left the East Bay Hills area completely susceptible to major fire devastation.

The lack of fire prevention techniques utilized in this area allowed the fire of 1991 to spread to gargantuan proportions, overwhelming almost every fire suppression method available. The lack of fire regulation on shingle roofs and clearance between natural fuels and structures can be directly associated with the destruction caused by the fire (Routley 1992). If people had enforced these regulations before the fire, many of the homes would have been saved. Also, access to water became a major problem during the fire because of poor planning. Most of the water supplies on the East Bay Hills were controlled with electric water pumps. When the fire destroyed the power supply to the area, the electric pumps could no longer keep the water supplies full, causing many hydrants to run dry (Routley 1992). Better fire planning would have eliminated the water supply problems and would have given the firefighters the resources that they needed to properly combat the inferno.

The 1991 East Bay Hills fire exemplifies the dangers associated with the wild land-urban interface. If fire protection authorities understand the dangers that people will encounter in this type of living, they will be able to better prepare themselves for the inherent hazards. Increasing the knowledge of wild land-urban fires will allow for better fire preparation and planning.

Fire Control Planning

Given the high fire danger in sprawling urban communities, fire control must be highly effective and intricately planned. Any inadequacy poses significant risk of disaster. In order to assist in fire planning, an understanding of factors relating to fire suppression is needed. Three extremely important issues concerning fire control and prevention are emergency response time, zoning, and environment. These firefighting fundamentals dictate the effectiveness of fire control.

Response time is critical to controlling outbreaks of fire. Davis (1986) identifies rapid response to fire incidents as the most important factor in fire control. Fire districts in Winston-Salem, North Carolina use computer technology to minimize response time. These fire districts use technologies, such as GIS, document imaging, mobile data computers, and computer aided dispatch, to provide fire fighters with critical information, improve decision making, and hasten emergency response (Conley and Lesser 1998). The GIS databases store the locations of items such as railway networks, pre-fire survey locations, fire department locations, hydrant locations, address locations, and school locations. Road networks, traffic patterns, and stop light control allows vehicle operators to determine the fastest routes to emergency scenes. Knowing these conditions allow planners to estimate response time to any location and identify areas with poor emergency response coverage, thus reducing the risk of fire disaster.

Proper planning can help alleviate fire risk. Robertson (1989) recognizes the need for proper zoning codes. For example, industrial areas tend to have a high fire danger. By zoning residential areas away from industrial centres, fire risk is reduced. Zoning can also be used to regulate the proximity of homes from natural fuel sources. Davis (1986) notes the importance of access to water supplies in minimizing fire danger. Both availability and mobility must be addressed to control fires. Regulations within residential areas can also reduce fire risk. The Fire Hazard Zoning Field Guide (2000) lists population density, construction materials and proximity to vegetation as factors influencing fire danger. Spacing structures further apart, creating vegetation buffers around structures, and creating fuel breaks and green zones hamper the spread of fire. Avoiding areas of high fuel concentration—such as those along urban-wild land interfaces—also decreases fire risk. However, the urban sprawl surrounding Melbourne places many structures in areas characterized by these risk factors.

Geography and climate also factor into fire risk. The Fire Hazard Zoning Field Guide (2000) cites steep slopes and dry climates as contributors to high fire risk. In general, fire expansion rate doubles for every ten degrees of uphill grade (Corporate Communications for Fire Management Department, 1993). The Dandenong ranges in Australia exemplify the high fire risk associated with hilly regions through their notorious fire history in the state of Victoria. Also, natural hazards such as canyons and cliffs can inhibit fire suppression techniques, thus increasing fire danger. In addition, areas subject to severe weather such as high winds and electrical storms typically have increased fire risk. Although these geographic factors cannot be controlled, identifying these areas allows communities to avoid growing into areas of high risk or increase fire control resources in dangerous areas.

In particular, Victoria is notorious for its "changes," a dangerous wind pattern that consists of an abrupt change from hot, dry northerly winds to cold, strong southwesterly winds. Fires extend from north to south with a narrow front in a teardrop shape until the wind shifts, creating a long front sweeping east. Figure 1 depicts the fire progression of the Ash Wednesday fires under the influence of Victoria's changing wind patterns. As seen in figure 1, the fire ignited at a single point labeled "origin". As the fire continued to burn under the influence of the typical northerly winds, the fire front produced a teardrop shape. At approximately 1900 hours, the winds shifted from the north to the southwest. This abrupt change in the wind patterns caused the entire eastern flank of the fire to become the new front, greatly increasing the magnitude of the fire. Victoria's changing wind patterns are very dangerous because the changing of the front puts fire fighters directly in harm's way and greatly expands the size of the fire in a matter of minutes. As seen in the figure, after the wind change the fire rampages in a northeastward direction, nearly tripling its size under an hour.

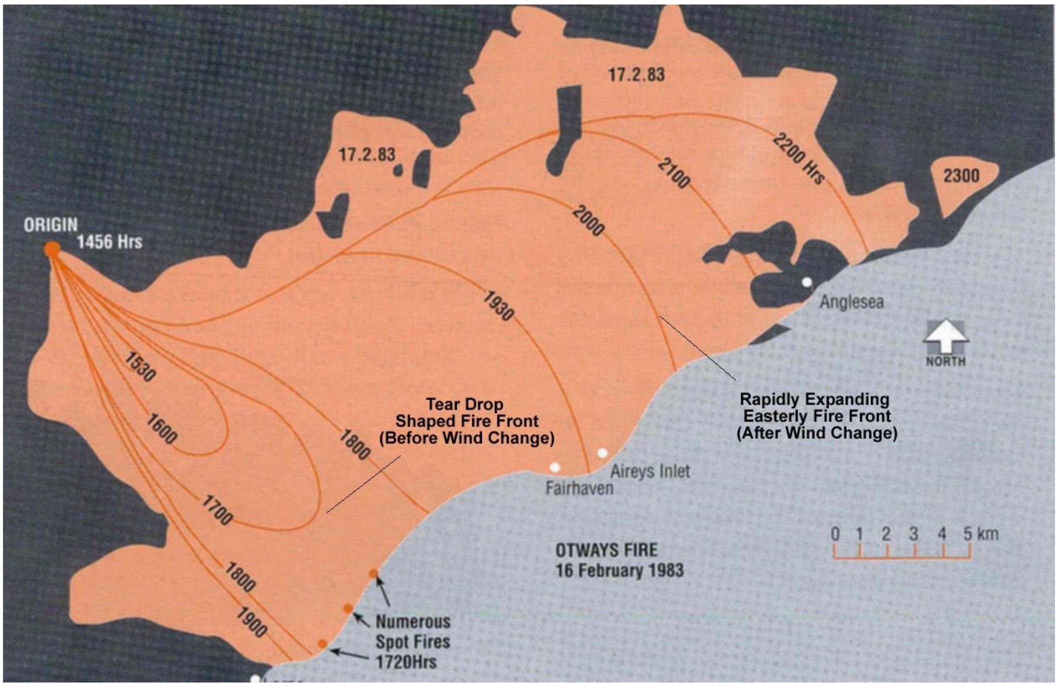


Figure 1. Fire Progression Influenced by Victoria's Wind Patterns
Adapted from <u>Bushfires: Living with Australia's Natural Heritage,</u> 1995, p. 11

This deadly phenomena is a major contributing factor to numerous severe fires in Victoria, including Ash Wednesday on January 8th, 1983 and the Linton disaster on December 2nd, 1998. In both cases, a sudden wind shift from northerly to westerly resulted in catastrophe (Country Fire Authority, 1999; Country Fire Authority, 1995). In the Ash Wednesday fires, forty-six of the forty-seven deaths occurred after the change of wind direction, which trapped firefighters and civilians alike. The dramatic fire spread occurring after the change is apparent in the fire near Otways on Ash Wednesday (See Figure 1). Likewise, the fire near Linton was nearing containment when a sudden wind change trapped two fire tankers on the east front, killing five firemen. This weather phenomenon makes Victoria extremely susceptible to catastrophic fires.

Although weather and geography cannot be controlled, fire disasters may be minimized by carefully planning community development. Considering emergency access when designing road networks decreases response time, helping to prevent large scale fires. Zoning for fire safety also limits the spread of fire through residential areas. These are critical, especially in areas with geographical features and weather conditions that increase fire risk. Appropriate fire suppression planning and fire awareness education require quantifying all of these factors that influence fire risk in order to make an overall assessment.

The Federal Wildland Policy for Wildland/Urban Interface Protection (1999) in the United States suggests developing and adopting a standardized fire hazard assessment model to allow effective policy development at the local level. Similarly, Australia, in 1999, adopted a new risk management standard, AS/NZS 4360:1999, that provides a standardized framework for hazard regulation (The Standards Association of Australia, 1999). To comply with this standard and confront Victoria's high fire danger, the Country Fire Authority is in the process of modifying their operations to include a focus on fire understanding and risk reduction by creating a proactive, state-wide fire management policy. In order to quantify the issues relevant to fires in Victoria and assess the fire hazard, a statistical model is needed. In addition, a uniform statistical model could empower local brigades to plan for fire safety.

Decision Support and the Role of Modeling

Before undertaking any project with the intent of aiding decision-makers in creating or changing policy, the effectiveness of modeling as a tool for evaluating options and selecting decisions must be addressed. Decisions concerning fire suppression planning on a community level require reliable information. Theoretically, planners may rely on predictive modeling as a scientific absolute that provides clear and definitive results (Copas, 1993). However, the science is irrelevant to a public service organization such as the CFA unless it can be applied in a practical sense. Many factors influence the applicability of a model, including political relevance, statistical confidence, model believability, and presentation clarity (Rejeski, 1993). Failure to satisfy any one of these criteria will compromise the ability of a model to influence reality. In Australia, a new national standard guides the development of modeling for risk management. Considering this standard along with the factors influencing model applicability aids the construction of a usable model.

Australia's New Risk Management Standard

In 1999, the Standards Association of Australia in conjunction with the Council of Standards New Zealand, released a new standard for risk management protocol titled *Risk Management*, AS/NZS 4360:1999. This standard serves as an update to the previous risk management standard, AS/NZS 4360:1995 and provides the criterion for risk context establishment, identification, analysis, evaluation, treatment, monitoring, and communication (The Standards Association of Australia, 1999). This document describes risk management as being a repetitive process in which a sequence of steps is taken to support the decision making process by increasing the knowledge of risks and their consequences. This iterative process is explained in detail throughout AS/NZS 4360:1999, providing insight on the numerous methods which can be used to build a comprehensive knowledgebase about a certain risk. One of the principal sections of AS/NZS 4360:1999, is the section on risk analysis and the study of risk consequences and likelihood. The risk analysis section of this standard deals with the identification and analysis of the risk affecting factors, focusing on the prediction of a risk's consequences and likelihoods. AS/NZS 4360:1999 states these consequences and likelihoods can be determined by using statistical analysis, modelling, past records, previous experience and by experiments (The Standards Association of Australia, 1999). Under the guidelines set fourth by this new standard, the CFA has decided to revamp their risk management policies in order to provide equitable fire protection services across the state of Victoria.

The CFA's model of fire cover documents the CFA's response to AS/NZS 4360:1999. Implementation of this risk management plan will align the organization with the new national standard. By focusing on fire hazards and methods to reduce risk, the CFA can promote fire safety by reducing risk before fires occur. In order to do this, the model of fire cover stresses an outcome-based approach to risk management that allows the use of unique fire management strategies in each community. This is accomplished by measuring a community's fire safety success by considering the fire damage incurred, as opposed to simply measuring fire fighting benchmarks such as incident response time, establishes a broader perception of fire safety. This new perspective empowers communities and brigades to support innovative fire prevention techniques such as fire awareness education. Outcomes measures will be used to test for equitable fire safety coverage and to make brigades and communities accountable for fire safety. To test the effectiveness of fire safety programs in a community, a benchmark is needed. By comparing the fires actually occurring to the benchmark of expected fire activity in an area, a level of fire safety can be assigned. Government officials require a usable fire model to generate this benchmarking information (Country Fire Authority: A Model of Fire Cover, 2001).

Political Relevance and Model Design

To impact society, modelling techniques must apply to the political world (King and Kramer, 1993). To achieve this impact, a researcher must understand the intended application of a model and construct theory in a manner compatible with the planner's needs. For example, a model of nation-wide fire frequency does not assist planning at the city level. Similarly, a model that merely identifies fire trends provides nothing to the planner unless accompanied by data relating these trends to the physical reality of the planner's jurisdiction (Goodchild, 1993). A lack of applicability to the physical world renders a model impotent. By specifying the type of information needed by specific planning organizations or governments, the researcher can tailor models to provide relevant results.

Model inflexibility and narrowness of scope create barriers that prevent the model from achieving political significance. King and Kraemer (1993) give the examples of the absence of models and projections in influencing the decisions of the German government. Since German scientific research has a history of being highly institutionalized, the research community prefers to avoid the political scene to preserve the public’s perceived infallibility in their research. This apparent perfection would be jeopardized should a model be used to support an unsuccessful agenda. This assertion of statistical prediction as an infallible and uncompromising method hinders adaptation to the political arena. Instead, recognizing the bias and error in modeling allows policy makers the flexibility to use information from models without being restricted to a model's results.

Goodchild (1993) argues that even a conscious focus on the political aspect of model development is insufficient to earn the respect of planners. Instead, models must pertain to a tangible threat to be consequential. He claims that without immediate and concrete phenomena to support theoretical prediction, changes in policy are rare. However, this argument applies only to recondite models such as early theories on ozone depletion. The imminent nature of fire in Victoria validates the development of fire modeling theory for application in policy.

Statistical Confidence and Model Design

The accuracy of predictions made by models directly influences the usefulness of models in policy decision-making. Due to the intrinsic uncertainty of knowledge as applied to statistical analysis and modeling, the predictions and trends produced are never perfect (Rejeski 1993). Both the modeler and the target audience need to understand the limitations of theoretical science and the magnitudes of error involved (King and Kraemer, 1993). Rajeski categorizes some of the uncertainties of the science into spatial uncertainty, linguistic uncertainty, and model uncertainty. Defining and investigating the implications of each error source provides a comprehensive overview of the factors involved in establishing a known level of statistical confidence.

The most apparent source of error, spatial uncertainty, refers to ambiguity in the original data that causes inaccuracies in the model analysis based on this data. Spatial uncertainty applies to nearly every model based on location-oriented information (Wadge, Wislocki, and Pearson, 1993). However, if the amount of uncertainty in a spatial data set is known, it is possible to characterize the variance, or average error, mathematically. While mathematical calculation can communicate the amount of error, Copas (1993) explains that if the accuracy or resolution of the data fails to describe the information at the level required by planners, no amount of manipulation can compensate. To avoid this potentially fatal flaw, data sets should be examined before model development. For example, when searching for links between social data and fire trends, both data sources being compared must have the necessary accuracy to draw relevant inferences. Without quality data, no modeling technique can provide results applicable to decision-making (Huxhold, 1991).

Linguistic uncertainty, as described by Rajeski, arises due to the abstraction of the English language. Every individual attaches different meaning to the same sets of words depending on culture, experience, and personality. For example, incongruities in the interpretation of the phrase "high fire risk area" will hinder the communication of fire risk model results. Explicitly defining terms help alleviate this problem. The attempt to portray statistical data with words is another source of linguistic error. Although describing results with words facilitates interpretation of the model results, the ambiguity introduced masks the accuracy of the model. Taking into account the thought process of the human mind allows the modeller to reduce this error (Hewitt, 1993). Researcher awareness of the perceptions of policy-makers ensures that the distortion will be minimized.

Model uncertainty arises due to failures in the theoretical construction of the model. Science and prediction techniques cannot completely mimic the complexities of reality (Rejeski, 1993). Causes of model uncertainty include misidentified causal relationships, generalized data groupings, and failure do identify all causes of an event. Minimizing this error requires a comprehensive knowledge of the event being modeled (Delaney, 1999). King and Kraemer suggest incorporating several models describing the same phenomena in order to identify and eliminate the biases of each model.

Model Believability

Believability relates to the need to secure the public's trust and enable politicians to accept the results of a study with confidence. Maintaining believability relies on identifying the limits of a model and honestly acknowledging where the predictions break down (Rejeski, 1993). Believability also depends on the representation of the results. A model may involve complex computations that combine many factors into a single summarizing value, or it may produce a variety of descriptive values that the individual must interpret to reach any sort of conclusion (Turk, 1993). If many components pertain to a decision, and the model produces a large set of facts or statistics, the user may be overwhelmed and unable to take all factors into consideration. Giving a planner several maps showing fire trends, possible causes, and fire fighting resources forces the planner to synthesize the material in order to take action. Instead of forcing the user to evaluate the information, a completely automated processing algorithm can produce overall summary measures. However, this method often produces seemingly unsupported results, especially if the process is not easily understood. Sometimes, results do not even have a specific unit of measure, but merely produce values relative to some arbitrary standard (Turk, 1993). If the fire prediction model categorizes the results into a single presentation of high, medium, and low risk areas, the planner is left to guess at the meaning behind the conclusions. Careful compromise will produce results that can be trusted by the public and clearly suggest a course of action to the policy-makers, both of which are necessary to create the believability that is required of any methodology.

Model Presentation Clarity

Presentation of the results and conclusions is the final step in modeling. The critical juncture between modeler and decision-maker, the presentation must be clear and coherent (Hirschfield, Brown, and Marsden, 1993). Without effectively bridging the gap between the scientific and the political, a model is useless. To accomplish this transition, the model developer must know both the model results and the possible implications of these results. Presenting results within the social context provides perspective that keeps the focus of the information relevant to the decision at hand (Rejesky, 1993). Effective communication is the last stage in applying modeling to public policy, and, if properly approached, makes a strong case for the results of a model.

Focusing on political relevance, statistical confidence, model believability, and presentation clarity in the model development causes the modeler to constantly assess the societal framework surrounding the research topic. This awareness of the overall significance of modeling guides research into a form that is both accessible to the general public and applicable to reality. The task of the modeler is to combine statistical methods in order to manipulate data to produce results that meet the criteria of relevance, confidence, believability, and clarity.

Statistical Methods

Creating models that provide useful and relevant results requires a working knowledge of statistical techniques. As discussed above, the validity and subsequent utility of any model relies in part on the accuracy and precision of the techniques used in the derivation. However, increased accuracy and precision generally require greater model complexity, and are ultimately limited by data precision and system stability, among other factors. Many statistical methods currently exist, each with unique strengths and weaknesses. When developing a model for a specific application, a general examination of the available statistical methods allows for proper model selection or exposes a need for innovative modeling techniques.

Basic Techniques

Regression, in its simplest form, provides a basic foundation upon which many modeling techniques are based. Simple linear regression with a single input or independent variable constructs a "best-fit" approximation of a given set of data consisting of input/output pairs, where the output is the dependent variable. Also known as least-squares estimation, the result is a linear model that minimizes the overall residual error, where residual error is measured as the square of the difference between the actual output and the output of the model at each input value (Pankratz 1991; Rawlings, 1988; Rousseeuw and Leroy, 1987).

After determining the parameters of a regression model for a set of data, a variety of measures may be used to classify the accuracy of the model. For comparisons between regression models or other similar models, Pankratz suggests “goodness of fit.” Goodness of fit involves averaging the ratio of the difference between the expected output and the mean output versus the difference between the actual output and the mean output. This statistic produces the proportion of the variation in the dependent variable that is due to the variation in the independent variable (Pankratz 1991; Rawlings, 1988). For example, in a model relating the number of fires in an area to the area's population density, goodness of fit measures the amount of influence population density has on the occurrence of fires. While goodness of fit provides an overall summary of a relationship between variables, the calculation suffers from distortion due to statistical bias. Although this cannot be eliminated, an adjusted value can be derived taking into account the number of parameters in the model (Pankratz, 1991). With this optimization, the proportions produced will be more indicative of reality.

Rawlings uses confidence interval estimates to show the accuracy of regression models, allowing for a natural extension from past data to future events. For a given probability, this interval bounds the fitted line given by regression analysis, depicting an area within which future events will occur given with the selected probability. Confidence interval estimates give a distinct visual representation of the certainty with which events can be predicted, which are often useful in presenting results. However, although this method provides clear visual comparison, it does not produce the concrete numerical values for proving model accuracy (Rawlings, 1988).

To demonstrate model fit for regression analyses, the t-test and the F-test are used (Pankratz 1991; Rawlings, 1988; Rousseeuw and Leroy, 1987). These methods test the validity of a hypothesis describing the nature of an observed data set against the parameters derived for the regression model. The t-test applies only to a single independent variable in regression, while the F-test extends to testing hypotheses for regression models with multiple independent variables (Pankratz, 1991; Rawlings, 1988). Combing these tests can provide the nominal evaluation of accuracy needed to for model fit analysis.

As a simple statistical technique, regression analysis is subject to many shortcomings. Pankratz argues that incomplete underlying theory often plagues regression studies. Data cannot be collected for all phenomena influencing the event being studied, and omissions are fatal. Wilson (1980) refutes this premise, claiming that model development based on a limited variety of pre-collected data constitutes a valid method. Although not ideal, time and financial constraints often necessitate the latter method. As long as sufficient correlation between independent variables and the dependent event being modeled is established, the unknown or immeasurable factors may be included in the uncertainty (Rawlings, 1988).

Other weaknesses in regression analysis include colinearity, outliers, and heteroskedastic disturbance, and autocorrelated disturbance (Pankratz, 1991; Rawlings, 1988). Colinearity occurs when regression analysis is extended to multiple input variables and the input variables are related to each other. This causes a redundancy of information that distorts the amount each factor influences the predicted result (Rawlings, 1988). Pankratz claims that this error often causes fundamental problems with the model, while Rawlings maintains that the overall predictive utility of a model remains uncompromised as long as the relation between the input factors stays constant. Outliers significantly distort the averages used to compute simple regression models (Rawlings, 1988; Rousseeuw and Leroy, 1987). However, a variety of methods exist that help identify and reduce the effects of outliers. Heteroskedastic disturbance refers to variances in the data that are not constant. More complex models are needed to deal with this phenomena disturbance (Pankratz, 1991; Rawlings, 1988). Autocorrelated disturbance occurs when variations in a data point influence variations in neighboring data. By taking this disturbance trend into account, model accuracy can be greatly increased (Pankratz, 1991).

Rousseeuw and Leroy present a variety of methods aimed at minimizing error due to outliers, heteroskedastic disturbance, and the restrictions of linearity. After mathematically determining which of the data available is most consistent, Rousseeuw and Leroy's methods omit up to half of the least-correlated information and fits a model to the remaining data observations. Because of the high complexity and computational intensity of these methods, these models are not used unless significant outlier error exists in standard regression (Rousseeuw and Leroy, 1987).

Spatial Statistics

Spatial statistics extends the concepts of basic statistical analysis into the geographic plane. Geographical data assigns attribute data to locations in two-dimensional space. Representing data spatially allows the relative locations of information to be included in statistical modeling (Berry, 1993; Griffith, 1996). The benefit is models that more accurately represent patterns found in reality. For instance, a simple model may use population density to predict the occurrence of fires. However, data on population density generally refers to large areas, with significant differences in density between neighboring areas. This simple model merely assigns a prediction for each area, assuming each area is distinctive and independent of its neighbors. At the boundary, one may move from an area of high fire risk to an area of low risk simply by crossing the street (Vasilev, 1996). Considering the spatial relations, or spatial correlations, between these areas of differing population density allows the modeler to smooth a fire prediction model. Also, similarities, or correlations, often exist between the fire predictions for neighboring areas. Geographic statistics allow this fact to be measured and included in model development.

Geographic Information Systems and Modeling

Geographic Information Systems (GIS) provide the data organization and computational tools needed to generate these complex spatial statistics. Based on a method of combining two-dimensional data fields, or layers, GIS allows sophisticated statistical computations to be calculated with respect to surface location (Berry, 1993). This ability is ideal for representing and modeling spatial trends. The previous success of developing GIS systems to facilitate an understanding of event occurrences suggests the feasibility and utility of creating a GIS-based model for fire prediction and suppression.

Critical to fire prediction and suppression is ability to assess fire risk. Hirschfield, Brown, and Marsden (1991) document a GIS project conducted to locate areas of abnormally low or high occurrences of salmonella poisoning in a region. A map layer containing the locations of food poisoning incidents was compared to population density layers. Statistically combining these layers provided the desired risk assessment. Because salmonella poisoning cases are infrequent, techniques to minimize the influence of a single occurrence in sparsely populated areas were developed (Hisrschfield, Brown, and Marden, 1991). Incidents of fire are comparable to salmonella poisoning. Fire data will also suffer from few data points in sparsely populated areas, requiring similar risk assessment methods to express relative levels of fire danger. Locating areas with abnormally frequent fires will aid in identifying trends associated with high fire risk.

Identification and analysis of the factors related to fire risk provides the foundation for developing a multivariate regressive model. Berry (1993) asserts that GIS can increase the utility of regression models by refining the resolution. He cites a model used in the logging industry used to predict the tendency of felled trees to crack depending on location. One of the factors was average tree height. However, the average height in an area did not reflect the tall trees on the steep slopes and short trees in the flats. Using GIS to combine tree height data with slope data, a representation showing tree height variation with respect to slope was produced that was then used to predict the cracking of felled trees. Similarly, spatial relationships may exist in the factors related to fires. For example, geographic depressions may collect precipitation runoff and correlate to lower fire risk. GIS will allows for these types of inferences to be tested and modeled.

GIS has also been used to assist in turning models into planning tools. Newkirk (1991) describes the Waterloo Generic Urban Model and its implications concerning the city of Toronto. He demonstrates the process of using GIS to aid urban planning by projecting the results of various planning decisions. Consequently, integrating fire prediction with urban development models could demonstrate the effects of urban growth on fire risk. Extending this idea, fire suppression measures could be modeled as well to assist in minimizing the occurrence and magnitude of fires.

Geographic Information Systems offer the tools to design and implement risk assessment and risk management modelling systems. Developing a GIS-based fire prediction model to impact policy and planning could assist in fire safety planning at the community level. As the city of Melbourne continues to grow, a properly designed model could provide decision support to help CFA officials combat the increasing fire threat.

Chapter 3. Methodology

Introduction

This project developed a statistical tool to assist the Country Fire Authority in Victoria, Australia through modelling fire risk. In order to develop this fire risk model, we conducted research to establish relationships between demographics, geographic location, and the frequency of CFA responses to emergency incidents. Quantifying the specific factors related to incidents generated statistical descriptions of the correlations to incident occurrences. We measured the influences of demographic components such as population and dwelling information, and integrated them into a mathematical system to produce an estimate of future CFA incidents in a given area. The project utilized databases existing in the CFA's GIS system to develop and implement this fire prediction model. The resulting tool has the potential to identify locations of high fire risk in order to aid CFA management in future planning.

To create this fire risk model, we developed an understanding of the Victorian fire threat and analysed incident data specific to the CFA’s jurisdiction. We researched information on high-risk areas, fire causes, and other fire trends using documents in the CFA library. Simultaneous to collecting this information, we examined data from the Australian Bureau of Statistics, the Department of Infrastructure, and the CFA’s Fire Incident Reporting System for trends in fire incident location. This research produced hypotheses on fire incident patterns. We selected databases currently existing within the CFA's GIS system that related to our hypotheses and showed correlations with fire incidents. These databases formed the foundation for the development of an incident forecasting model. After testing the forecasting model, we presented the model to CFA officials for use as a fire risk assessment tool with potential applications in fire control planning.

Metadata Research

We interviewed representatives from the Department of Infrastructure, the proprietor of the land release data used for incident forecasting, to gain information about the residential projections vital to our incident forecasting. In addition to providing us an understanding of the data, the collection of metadata, or data about the data, gave us the information required to make the model believable. This information included data collection techniques, data collection history, the age of the data, and the derivation of the calculated figures. From the metadata, we determined the appropriate methods of including the data in our predictive model.

Database Search

The background research provided us with a set of factors relevant to fire incident trends. We then determined which of these factors were represented by the databases archived in the CFA. An initial analysis of the correlations between the GIS databases describing these factors and the CFA incidents ascertained which factors actually relate to the fire occurrences. A systematic process of identifying, analysing, and summarising relationships created a library of comparable correlation results from which a model was derived.

The CFA archives many databases in their GIS system. These databases include information on demographics, economics, emergency incidents, road systems, and geography. Research was required to seek patterns in the location of emergency incidents as related to other databases with an emphasis on demographic information.

To assist in the comparison of relationships, a systematic analysis routine for inspecting the databases was established.

Initially, all of the data sets were stored in ArcView GIS software format (ArcView GIS, 2000). As data in a GIS system, all of the information contained spatial attributes mapping the data to locations. Using ArcView, each data set, or GIS theme, was displayed visually over an outline of Victoria. Layering the incident locations over the theme being analysed allowed for a visual comparison. From this visual comparison and the background research, hypotheses were formed about possible correlations to emergency incidents. To test the hypotheses, the data were exported from ArcView to Microsoft Access (Microsoft Access, 2001). In Access, the data were studied and refined to identify errors or inaccuracies and remove redundancies. Most data sets required grouping or other manipulation to summarize sections of data into organized collections and facilitate analysis.

After analysis and data manipulation in Access, the data were moved into Microsoft Excel to produce summary measures, display scatter plots, and calculate trend lines (Microsoft Excel, 2001). Summary measures established state-wide values to be used as standards for comparison to local statistics. The scatter plots graphically displayed the data behaviour and often suggested trends. To numerically quantify these trends, Excel was used to conduct a regression analysis, calculating a line of best fit to match the plotted data. This produced an R^2 value that reflected the randomness of the dependent variable with respect to the independent variable, where a value of zero indicates complete randomness and a value of one indicates no randomness. The results of the each Excel analysis were summarized and compared to the original conjectures. Comparing the outcomes to the hypotheses while considering the data manipulation allowed for insightful interpretation of the data.

Model Development

After establishing the factors involved in CFA incident forecasting, a more rigorous analysis was conducted. By measuring the correlation between the recorded incidents and each of the pertinent data sets, a numerical value quantifying the influence the factors was determined. After investigating a variety of databases, we selected the most promising to be used as a model.

The model was tested for accuracy and precision to demonstrate its value as a reliable incident forecasting tool. Applying our model to the observed data produced an incident prediction that was compared to the documented incidents. This calculated a measure of accuracy and allowed us to create error estimates for the model forecasts. Error estimates clearly communicate the level of reliability in the model to CFA administration, ensuring proper use of the model results for planning and resource allocation decisions. Recommendations based on the products of the statistical model were made to the CFA. In addition, recommendations on any alternative techniques, such as system dynamics, were presented. Documentation of our methodology and modelling techniques allow the CFA to repeat this analysis as the demographics change and more data is collected, or extend the applications of the incident forecasting model to other fire-fighting organizations.

Chapter 4. Data Analysis

Background of Databases

The statistical querying, model development, and fire incident projections used in our analysis were dependent upon the many databases maintained in the CFA archives. These databases were obtained by the CFA from numerous sources, such as the Australian Bureau of Statistics, the Department of Infrastructure, and Intergraph Public Safety emergency dispatching service. Clear descriptions of both the information contained within these databases and the metadata on each database were necessary to properly conduct a statistical study and interpret its results. When the metadata for a specific database was insufficient to allow proper interpretation of the data, we contacted the original proprietor of the database in order to retrieve the necessary background information. The required metadata information included topics such as collection date, collection method, and data field descriptions. The CFA databases most critical to this study were the Fire Incident Reporting System (FIRS) records, Victoria's population and dwelling census information, and the Department of Infrastructure's residential development forecast data.

Fire Incident Reporting System Records

The Fire Incident Reporting System, or FIRS, is a system that catalogues all incidents to which the CFA responds. This database is owned by the CFA but both the CFA and the Intergraph Public Safety Company update the database with newly occurring incidents. For every CFA involved incident, information such as date, CFA region number, incident number, incident description, and the geographical location of the incident are recorded. The information stored in this database originates from emergency calls which all pass through Intergraph Public Safety before they are directed to the appropriate emergency response service. If an incident requiring CFA involvement enters the Intergraph Public Safety's dispatching system, the CFA is notified of the emergency and a record of the incident is entered into the FIRS database. Intergraph Public Safety is responsible for assigning a geographical location to every incident because they receive the location of the incident directly from the emergency call. The CFA is responsible for recording all other incident related information such as incident type and description. The brigades responding to each incident report descriptions of the specified incident for inclusion in the database and also have the right to alter the incident's geographical information if necessary. Short descriptions of the relevant fields from the FIRS databases are listed in Table 1.

Table 1. Relevant FIRS Data Field Descriptions

FIRS Data Field	Description
Region Number	CFA region in which the event occurred
Incident Number	Unique reference number
Incident Date	Date of CFA's response to the incident
Incident Description	Brief description of the incident
SDAP Description	Categorized event classification
Event Type	Emergency or non-emergency
Geographical x-coordinate	Location information
Geographical y-coordinate	Location information

Of particular importance is the Service Delivery Analysis Process (SDAP) description, which categorizes each event into one of fourteen categories. The different SDAP categories are shown in Table 2. The SDAP descriptions were very useful for discerning between the different types of events, which required CFA involvement. The SDAP description field allows the FIRS incident database to be broken down into types of incidents such as structural fires or all fire related incidents. The ability to distinguish between the different types of incidents allows for the spatial analysis of a selected type of incident rather than all CFA incidents together.

Although the ability to examine individual CFA incidents is inherent in the database, this study examined the spatial correlations of all CFA incidents.

Table 2. SDAP Data Field Descriptions

SDAP Data Field	Description
Structure fires	Building fires
Non-structure fires	Garbage fires
Open structure fires	Fences, electrical poles and transformers
Vegetation fires	Wildland or grass land fires
Undefined fires	Unauthorized burning
Roadbound vehicle fires	Motor vehicle fires
Vehicle incidents	Motor vehicle accidents
Spillage or leakage incidents	Hazardus material clean up
Downed powerlines	Removal of damaged powerlines
Support of other services	Support to other emergency services
Community service	Public service / Animal rescue
False alarms	False alarms intentional and unintentiona
Other incidents	Other

The FIRS database provided us with the necessary CFA response events to develop a spatial correlation between demographic information and CFA responses. The FIRS database was the primary source for the spatial mapping of CFA involved emergencies.

1996 Census Data

The Australian Bureau of Statistics conducts a national census every five years, collecting information such as populations, demographics and other socio-economic information. Because the 2001 census results had not been published at the time of this project, the 1996 census offered the most recent demographic information available in the CFA's databases. The census data is divided into several tables in the CFA's GIS files. These tables included census collection district boundaries, census collection district derived postal code boundaries, population statistics, and spatially mapped dwelling density information. This project utilized the population and dwelling statistics from the 1996 census.

The smallest unit of measurement for all collected statistical information released by the Australian Bureau of Statistics is the Census Collection District, or CCD. These CCDs are arbitrary geographical boundaries dividing the state into data collection zones, each intended to contain approximately two hundred households. However, because of changes in population and residential development, the actual number of households in each zone varies considerably. The 1996 census data in the CFA archives summarized information from 7,966 CCDs across the state of Victoria, 4,493 of which are under CFA jurisdiction. Map 1 displays the CCD boundaries in the Melbourne region. Entries for all CCDs are in both the population and dwelling databases. The census data fields from the population and dwelling databases used in this project are listed in Table 3.

Table 3. Relevant Census Field Descriptions

1996 Census Field	Description
CCD Code	Unique reference number
Area	Area of each CCD (in hectares)
Population	Population of each CCD
Population Density	Population density of each CCD
Dwellings	Number of dwellings in each CCD
Occupied Dwellings	Number of occupied dwellings
Unoccupied Dwellings	Number of unoccupied dwellings
Dwelling Density	Dwelling density in each CCD

In conjunction with the publication of CCDs, the Australian Bureau of Statistics also produced a set of boundaries known as CCD modified postal code areas. These regions are similar in theory to the CCDs, but are much larger in size, as shown in Map 2. On average, a postal code area or POA is ten times larger than a CCD. Each postal code area is assigned a unique numerical identification number, which assists with postal transactions, much similar to the United States' zip code system. Due to the fact that most of the postal code boundaries do not coincide with the CCD boundaries, the Australian Bureau of Statistics modified the POA boundaries, forming CCD derived POAs. The postal code areas are important to this spatial analysis because they provide a means for examining the spatial data over much larger subdivisions, rather than at the CCD level.

The Australian Bureau of Statistics databases were used as the primary sources for historic demographic and socio-economic data. All forecasted demographic and socio-economic data used in this analysis originated from the Department of Infrastructure's databases.

Department of Infrastructure Land Release Data

In order to project future population patterns, we included recent and impending land release information into our statistical model. The land release data used in this analysis was developed by the Department of Infrastructure in 1999 and published in 2000. The land release areas present in the Department of Infrastructure's forecast are described as sections of land that are scheduled for development. The scheduled dates for land development are approximate values developed by the Department of Infrastructure and range from five years to over eleven years. In this case, the land release areas we are concerned with are all intended for residential development. We examined the residential land release areas in the state of Victoria because these areas will change the dwelling distribution around the city of Melbourne, thus changing the number of CFA incidents. The Department of Infrastructure land release database includes numerous fields of data (See Table 4) about each land release area.

Table 4. Development Forecast Data Field Description

Residential Forecast	Description
Site ID	Unique reference number
Municipality	Town name of land release
Timing	Forcasted development date
Dwelling Density	Dwelling density of release area
Area (Hectares)	Area of land release
Dwellings	Number of dwellings in release area

The dwelling density information within the development forecast database was critical to the forecasting of CFA incidents. This information allowed us to calculate the number of expected dwellings for each residential development. In addition to the dwelling density information, the timing information was also critical to the forecasting of future incidents. The timing information incorporated a temporal element to the correlation between dwelling density and CFA incidents. The timing data field, which is used to describe the development date for each land release area, has seven possible values and each value is described in Table 5.

Table 5. Land Release Timing Field Description

Timing Field Value	Description
FD1	Land released in 1999
FD2	Land released in 1998
FD3	Land released in 1996
Short	Develop in 1-5 years
Medium	Develop in 6-10 years
Long	Develop in 11+ years
Non-Forecast	Undeterminable

The Department of Infrastructure in Victoria forecasts the land release areas by spatially analysing demographic trends, cadastral information, and development planning schemes supplied by organisations such as the Australian Bureau of Statistics, Department of Natural Resources and Environment and from local land development companies such as Delfin. The Department of Infrastructure analyses the data collected from these organisations and compares the results to zoning restrictions placed on certain areas of land by each shires' governing council. This comparison allows the Department of Infrastructure to estimate the construction timelines and geographical locations of land development. Through interviewing Department of Infrastructure land development analysts, we learned that, although the geographical locations of development areas are generally correct, the Department of Infrastructure slightly underestimated the rate at which some areas were recently developed. The Department of Infrastructure feels as though some areas are developing much quicker than their forecasts suggest due to extremely successful marketing campaigns conducted by land development companies. This could signify that even more land will be developed than previously projected by the development forecast.

In addition to the Department of Infrastructure interviews, we conducted a ground truthing study to investigate the accuracy of the development forecast data. The ground truthing study consisted of travelling to areas with significant amounts of forecasted land release and visually ensuring that the development process occurring in these areas correlates to the Department of Infrastructure's land development forecast. The results of the ground truthing study confirmed that the Department of Infrastructure's land development forecast accurately predicted the actual land development in these areas. A detailed discussion of the ground truthing study is located in appendix F.

The Department of Infrastructure development forecasts were used as the primary source for the land release data. All land development projections used in this analysis originated from this database.

Analysis Procedures

In order to search for links correlating CFA events to other information such as demographic patterns, we investigated the selected databases using a combination of software packages and analysis techniques. The correlation investigation processes and results for relating the population and dwelling data from the 1996 census to the FIRS events data are described below.

Software Packages

The software packages used in this analysis consisted of ArcView GIS 3.2, Microsoft Access 2000, and Microsoft Excel 2000. ArcView GIS 3.2 was used to find spatial correlations between various GIS databases such as CFA incidents and dwelling densities (ArcView GIS, 2000). ArcView was also used to import and manipulate relevant data within the CFA database. Separate databases were formulated from the imported data. The new databases allowed for the discovery of correlations to be mathematically modelled. Microsoft Access was used to manipulate the GIS data in tabular form (Microsoft Access, 2001). Microsoft Excel allowed us to perform modelling computations and regression analysis (Microsoft Excel, 2001).

Dwelling Data Investigation

Because Victoria's Department of Infrastructure plans future residential development in terms of number of dwellings allotted to a specific area, the first research attempted to correlate the dwelling information from the 1996 census to the FIRS events. Through research, we hypothesized that areas with high dwelling densities experience a disproportionately high fire risk. Therefore, high dwelling density areas would coincide with areas of high CFA activity. Visual analysis confirmed this hypothesis. Statistical analysis showed reasonably strong support for the hypothesis, although this degree of support varied greatly depending on the interpretation of fire risk. Refining the analysis and focusing on fire incidents verified the trend of high fire risk correlating to high dwelling density.

To visually assess the correlation of the 1996 dwelling data to the FIRS CFA incidents, we layered the corresponding GIS themes in ArcView. The majority of Victoria's geography is sparsely developed, with geographically small pockets of high dwelling density in and around the cities and towns, especially Melbourne and Geelong. Map 3 details the 1996 dwelling densities in the Melbourne area, along with forecasted residential development. Overlaying the FIRS incidents from each year separately showed consistent clustering of the incidents around these high dwelling density areas, with sparse incident densities throughout the rest of Victoria (See Map 4). The obvious exception to this trend occurs in inner Melbourne, which has a high population density and very few recorded incidents. This area corresponds to the jurisdiction of the Melbourne Fire and Emergency Services Board, or MFESB, where the CFA occasionally responds to give assistance and support. To confirm the visual correlation of dwelling density to CFA incidents, excepting the MFESB jurisdiction, we exported the census data to Microsoft Access and continued the investigation.

Because the FIRS database did not accurately reflect the incidents occurring in the MFESB jurisdiction, and the CFA responded to very few incidents in this area, the scope of the investigation was narrowed to include only CCDs whose centres lay outside of the MFESB jurisdiction. Of the 7,966 CCDs in the census, 4,493 met this criterion. The excluded CCDs contained only 2,244 of the 91,525 incidents recorded in the FIRS database from 1999 to 2001, so little information was lost by making this selection.

In Access, we summed the number of FIRS incidents in each CCD. This value, along with the number of dwellings and the area of the CCD as recorded in the 1996 census, provided sufficient information to complete initial correlation analyses. We recalculated the dwelling density for each CCD by dividing the dwelling counts by the CCD areas because the dwelling densities stored in the GIS database had insufficient precision and caused rounding error. Plotting each CCD's dwelling density versus the number of incidents recorded in the FIRS database (See Figure 2) showed no discernable correlation. Several CCDs stand out. For example, one CCD contained 948 incidents from 1999 to 2001, well above the average of 19.9 incidents per CCD for the same time period. In total, seventy-seven CCDs experienced more than one hundred incidents in these three years. The maximum dwelling density for a CCD is 44.3 dwellings per hectare, while the average is only 4.2 dwellings per hectare.

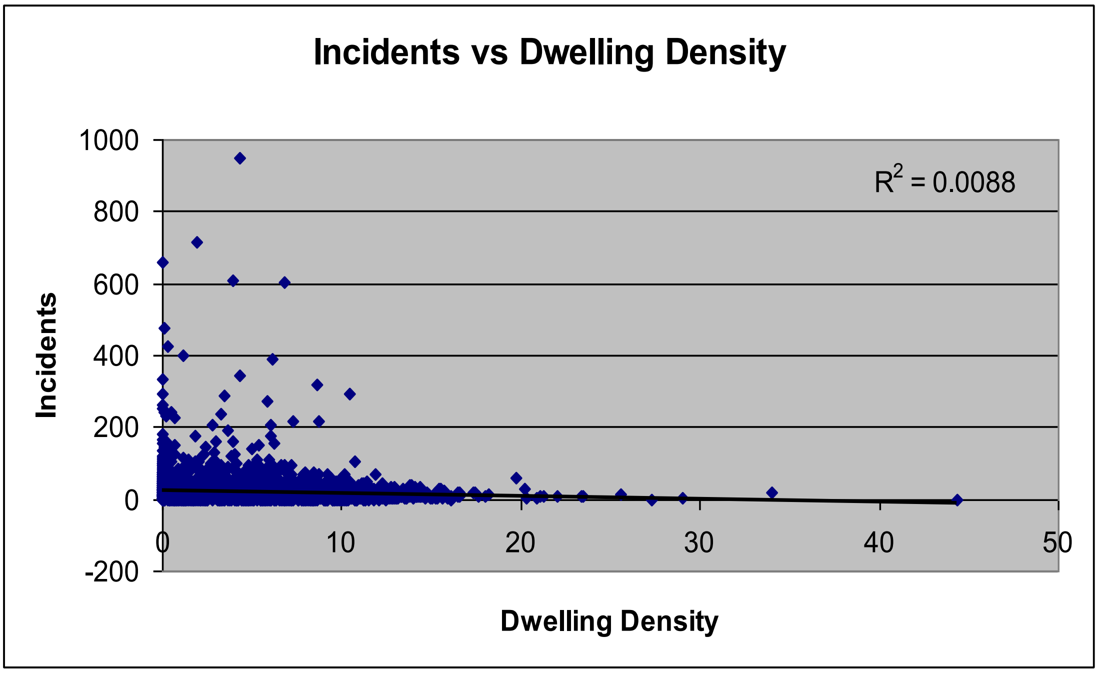


Figure 2. Total Incidents (1999-2001) vs 1996 Dwelling Density

Because CCDs vary in geographical size, number of dwellings, and population, we applied several normalizing techniques to minimise the effects of these variations. Depending on the nature of each investigation, we normalized with respect to CCD, area, population, or dwelling count.

Originally intended to contain approximately two hundred dwellings apiece, CCDs vary drastically in geographical area between urban and rural locations. Normalizing the dwelling density vs. CFA events plot by area (See Figure 3) produced a slightly rising trend, although the correlation remained extremely weak. This implied that areas with high dwelling densities might generally have high incident densities as well.

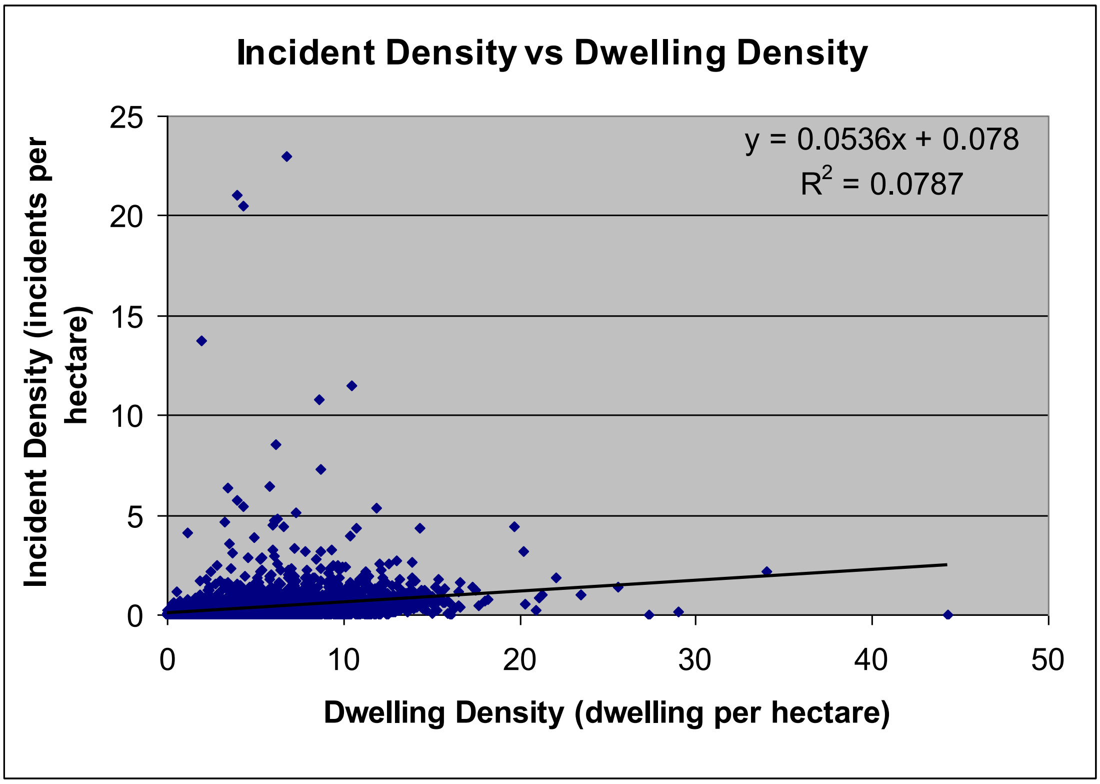


Figure 3. Incident Density (1999-2001) vs 1996 Dwelling Density

To summarize the 4,493 CCDs being analysed, we used various grouping methods to amalgamate the information into a manageable number of data points. Summarizing in this manner also helped expose trends that we could not identify in the plot with all of the CCDs displayed individually.

Collecting all CCDs into dwelling density classes with a range of 0.5 dwellings per hectare condensed the information into forty-eight data classes, the first class representing all CCDs with dwelling densities greater than or equal to zero dwellings per hectare and less then 0.5 dwelling per hectare, the second class representing all CCDs with dwelling densities greater than or equal to 0.5 dwellings per hectare and less than one dwelling per hectare, etc. Plotting these dwelling density classes against the total number of incidents in each class (See Figure 23, p. 98) showed a drastic decrease in incidents as dwelling densities increase. However, this relationship reflected the distribution of CCDs into the dwelling density classes (See Figure 24, p. 98) rather than a dynamic trend applicable to modelling. Clearly, the majority of incidents in the FIRS database occur in areas of low dwelling density, but this is merely because most of the CCDs have low dwelling densities. Thus, this analysis alone does not help determine fire risk in a specific area.

We normalized the dwelling density class information to minimise the distortion due to the disproportionate distribution of CCDs into dwelling density classes. Dividing the number of incidents in each class by the total number of dwellings in each class produced a linearly decreasing trend (See Figure 25, p. 99) with a reasonably high correlation ($R^2 = 0.50$). This normalization removed the severe extremes created by uneven distribution. The fire risk interpretation remained unclear. Although the plot suggested that few events occur per dwelling in areas of high dwelling density areas, this does not translate to greater fire safety in high dwelling density areas than in low dwelling density areas. Where dwellings are closer together, a single fire event is more likely to have involved multiple dwellings.

We normalized the dwelling density classes with respect to area, as well (See Figure 26, p. 99). This produced an $R^2 = 0.14$. Inspecting the plot revealed that the linear trend broke down beyond the 15.5-15.99 dwelling density class. Considering only the lower dwelling density classes (See Figure 27, p. 100) improves the correlation dramatically ($R^2 = 0.84$). Also, the interpretation to fire threat for this trend was clear. High dwelling density areas incurred a high density of incidents, implying significant fire risk.

Both to further reduce the bias caused by skewed distribution in dwelling density classes and to ensure the discovered trends were not merely artificial artefacts created by an arbitrary grouping technique, we sorted the CCDs by dwelling density and summarized the information in sequential groups of one hundred CCDs each. This approach produced nearly identical results, with the added benefit of moderating the outliers by grouping them with other values. Normalizing by dwelling (See Figure 28, p. 100) produced $R^2 = 0.53$ and normalizing by area (See Figure 29, p. 101) produced $R^2 = 0.86$. Because the latter showed the strongest correlation, we applied the regression equation to the known dwelling densities to compare the modelled number of incidents to the actual number of incidents recorded from 1999 to 2001 in the FIRS database. This modelling exercise produced extremely poor results. The model expected 1,445,269 incidents in the three-year period, opposed to the 89,281 incidents that actually occurred, a 1,519 percent error. This error originated from the wide variation of incidents occurring in CCDs of similar dwelling density. This suggested that the diverse conditions occurring across the state of Victoria inhibits the creation of a single model applicable to the entire state.

In an attempt to narrow the analysis to a more predictable scope, we examined only the fire incidents in the FIRS database. Again grouping both by dwelling density classes with ranges of 0.5 dwellings per hectare and by adjacent groups of one hundred CCDs each, the same analysis was performed. This analysis produced similar results (See Figure 30-Figure 35, p. 101-104). Like the analysis including all incidents, the variations in incident counts across the state prevented model development. Including the standard deviation when plotting the fire incidents in dwelling density groups of one hundred CCDs (See Figure 36, p. 104) demonstrates the large variations in number of fire incidents.

Despite the insufficient accuracy for modelling purposes, the direct relationship between dwelling density and incident frequency was established. This relationship coincided with our background research and confirmed our hypothesis. Thus, urban expansion creates an increase in fire incidents and raises fire risk. However, further investigation was needed in order to develop a predictive model.

Population Data Investigation

In an attempt to find a trend in incident occurrence with a stronger correlation, we investigated the population data from the 1996 census. Intuitively, population density and dwelling density are very similar statistics. Areas with low dwelling densities typically have low population densities as well. However, factors such as unoccupied dwellings decouple population and dwellings. We hypothesized that high population density would correlate to high fire risk, similar to the dwelling density findings. Furthermore, we believed that the relationship between population and incident occurrences would have greater correlation and facilitate model development.

Using the most promising relationship from the dwelling density analysis, we investigated the correlation between the population density of CCDs and the incident density within CCDs. Because of the disproportionate number of CCDs with low population densities we sorted the CCDs by population density, created groups of one hundred CCDs each, averaged the population density within each group, and averaged the incident density within each group. This analysis (See Figure 37, p. 105) showed the expected direct relationship between population density and incident density. However, the $R^2 = 0.77$ produced by this plot was less than the $R^2 = 0.86$ produced by the linear regression line correlating fire incidents to dwelling density. The population density evaluation confirmed that high population indicates a high number of incidents, suggesting that population growth increases fire risk. Because of the population density and dwelling density are highly dependent on each other, they contain nearly the same information. In this case, dwelling density provided a slightly stronger correlation to incidents than population density, but both the population density and dwelling density correlations to incidents expose the same phenomena: increased human habitation corresponds to increased CFA incidents. Because of the availability of projected dwelling statistics in Victoria's growth corridors and the higher correlations found using dwelling data, the dwelling density statistics the remained the primary database for modelling.

Postal Area Analysis

Although we were able to establish relationships between dwelling density, population density, and incidents, we needed to develop stronger relationships with less variation in order to use regression analysis to forecast future incidents. To accomplish this, we switched from analysing data at the Census Collection District level to analysing data at the Postal Area, or POA, level. POAs were approximately ten times larger than CCDs. Using CCD derived POAs decreased the data resolution, so information from each POA summarized several CCDs. We hypothesized that this grouping would reduce variations in the data and create a stronger correlation between dwellings and incident occurrence.

Using ArcView, we isolated the 493 POAs in the CFA's jurisdiction. To test the hypothesis, we plotted the number of dwellings in each POA as recorded in the

1996 census against the total number of incidents recorded in the FIRS database from 1999 to 2001 (See Figure 38, p. 105) and confirmed the trends shown in the dwelling density and population density analyses. POAs with many dwellings generally incurred a high number of incidents while POAs with few dwellings incurred a low number of incidents. With $R^2 = 0.83$, the correlation was not as strong as the incident density to dwelling density correlation. On the other hand, there was less variation within the POA data.

Model Development Using POA Dwelling Densities

Because of the promising initial results that correlated dwelling counts of postal areas to FIRS incidents from 1999 to 2001, we investigated the relationship further and developed a regression model. To ensure the validity of the regression trend line found in the previous analysis, we needed to better understand both the POA dwelling density data as recorded by the 1996 census, the FIRS incident data from 1999 to 2001, and the Department of Infrastructure residential land release information. Also, we needed to address the time difference between the collection of the census data and the collection of the incident data.

Separating the FIRS incident information by year revealed a significant increase in recorded CFA incidents each year (See Figure 4). The magnitude of the increase seemed unreasonably large, especially the 11 percent increase in incidents from 2000 to 2001. Experienced CFA employees quickly discredited this trend, explaining that such an increase would have overwhelmed the CFA, suggesting that the FIRS database misrepresented the actual occurrences of incidents throughout the CFA. Chris Cowley, the CFA employee responsible for managing the FIRS database, informed us that 1999 was the first full year that the Fire Incident Reporting System was used by the CFA. Therefore, the increase in incidents reported over the three-year period probably reflected the growing acceptance of the reporting system throughout the organisation. By this theory, each subsequent year's information recorded the CFA incidents more accurately, with the 2001 incidents best reflecting CFA activity. We concluded that the model should include only events recorded in 2001.

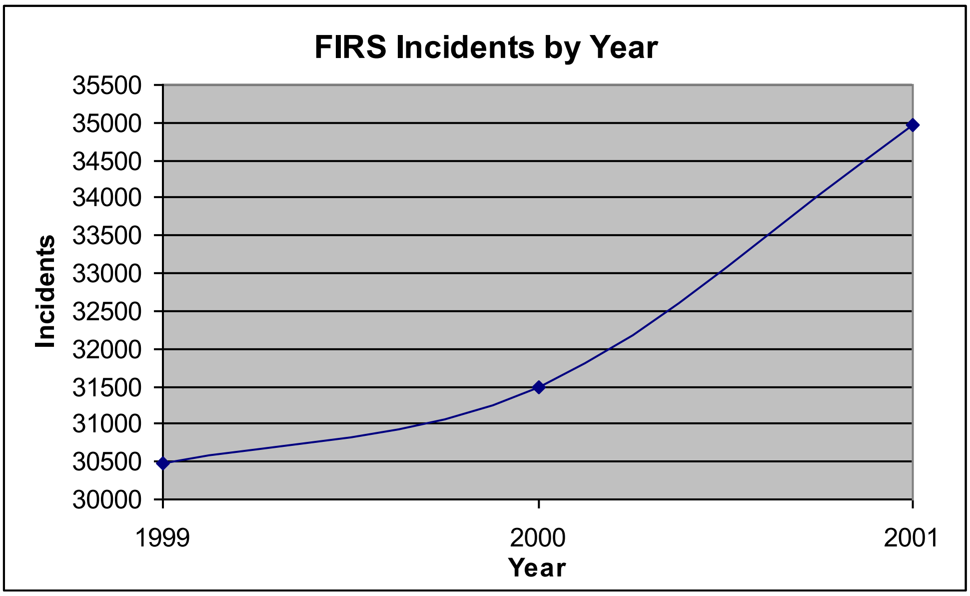


Figure 4. FIRS Incidents by Year

Using only the FIRS incident data from 2001 created a five year difference between the collection of the dwelling density data and the incident data. Within this time lag, the actual dwelling densities could have changed significantly. To fill in this gap as much as possible, we used the Department of Infrastructure information on residential land releases. The land release data contained the projected number of dwellings in each release area, along with the time of development. We included the dwellings planned for land releases in 1996, 1997, and 1999. The land release data did not have information on 1998 development. We determined the number of new dwellings due to land releases in each postal area and added this to the number of dwellings recorded in the 1996 census. This assumed that all potential dwellings within each land release were built within a year of the release.

Because the strongest relationship discovered within the CCDs was between dwelling density and incident density, we conducted a correlation analysis relating the dwelling densities of the POAs to incident density. The plot of 1999 POA dwelling densities against the incidents recorded in the FIRS database in 2001 (See Figure 5) produced an $R^2 = 0.37$, a far weaker correlation than that observed at the CCD level. The regression line was significantly skewed by a single outlier, POA number 3852. This POA had an area of only 0.74 hectares, drastically less than the average POA area of 49,934 hectares. Because of the extremely small area of the POA and the twenty-five dwellings within it, the dwelling density was much higher than any other POA. Removing this point eliminated less than 0.01 percent of Victoria's dwellings and strengthened the relationship to an $R^2 = 0.82$ (See Figure 6), confirming the strong correlation observed at the CCD level.

Although the relationship between dwelling density and incident density was strong, it could not be easily applied to the available residential growth information to forecast incidents. The residential land releases were generally small, changing the dwelling densities of their respective POAs by very little. The sensitivity required to measure slight changes in dwelling density made modelling impractical. As an alternative, we conducted a dwelling count correlation to 2001 incident occurrences using POAs.

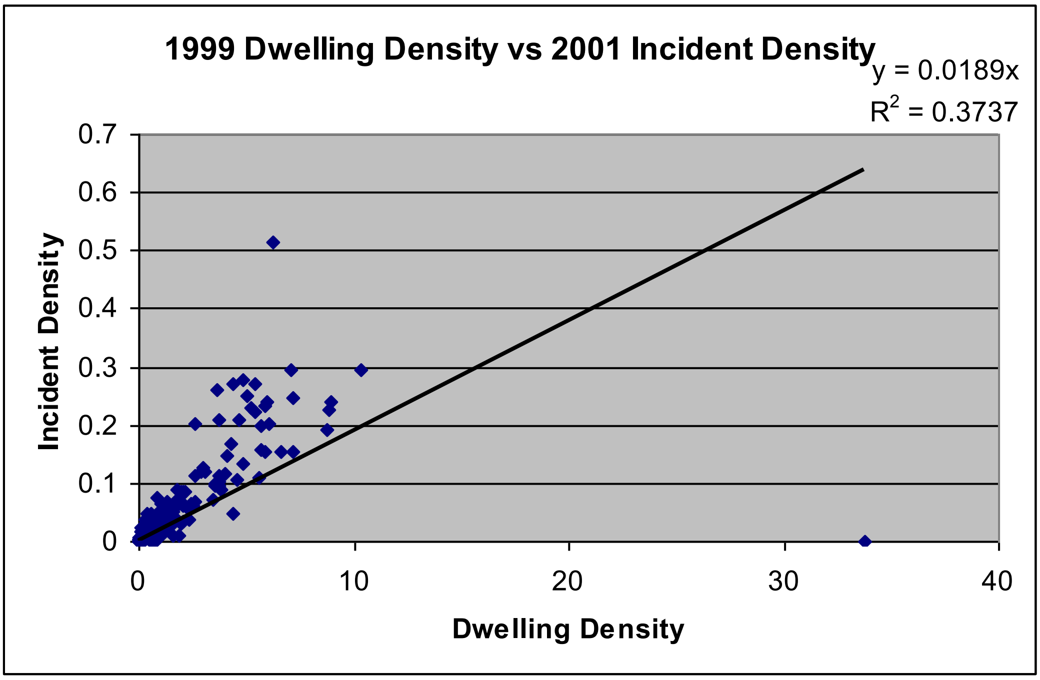


Figure 5. 1999 Dwellling Density vs 2001 Incident Density

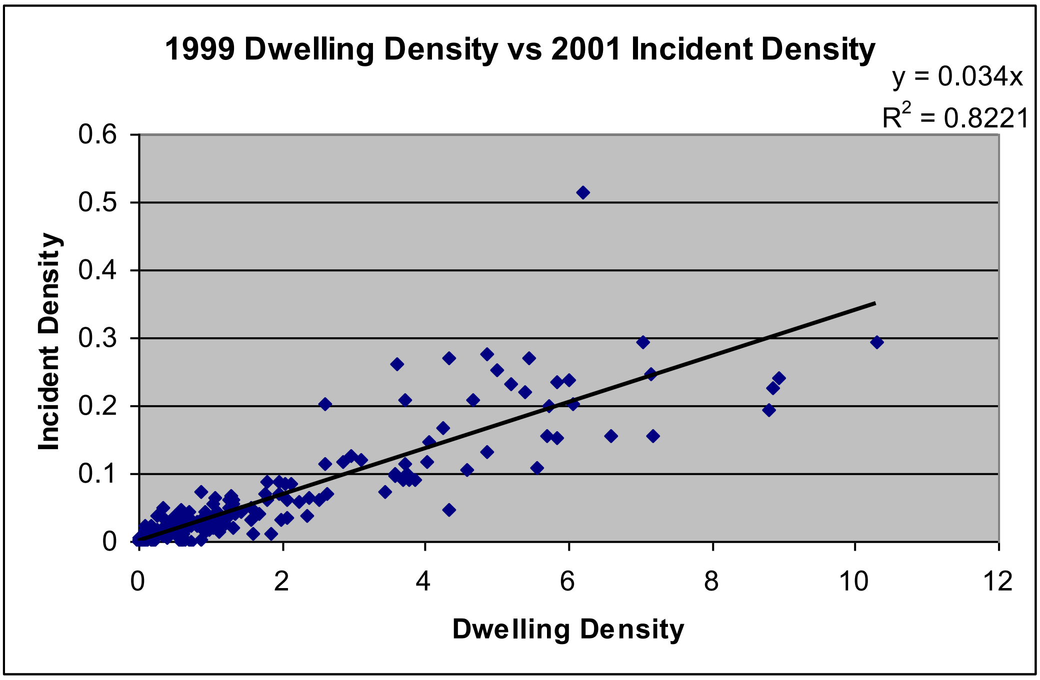


Figure 6. 1999 Dwelling Density vs 2001 Incident Density (Outlier Removed)

Plotting the estimated 1999 dwelling counts in relation to the 2001 FIRS incidents (See Figure 7) produced nearly the same pattern showed in the plot of the 1996 dwelling counts in relation to 1999 to 2001 FIRS incidents (See Figure 38, p. 105). The linear regression line of best fit was anchored at the origin to prevent negative incident projections. This produced a trend line with a slope of 0.0398. Relating the 1996 census dwelling figures to 2001 FIRS incidents (See Figure 8) produced a trend line through the origin with a slope of 0.0417, slightly more steep than the one calculated using the estimated 1999 dwelling counts. This suggested that if the number of dwellings had continued to increase until 2001, when the incidents were recorded, the slope of the regression line would be slightly less than 0.0398. However, the most current Department of Infrastructure publication had been released in 2000, and could not include residential construction from 2000 and 2001. The lag between the beginning of residential development and the completion and habitation of a residential area blurred the time classification and lessened the significance of the lack of 2000 and 2001 residential development data.

We used the linear regression line calculated from the relationship between the projected 1999 dwelling counts and the FIRS 2001 incident data as a model for incident forecasting. Applying the previously established model testing process, the regression equation was applied to the 1999 dwelling estimation. Comparing the forecasted incidents to the 2001 FIRS incidents produced an average incident forecast error of approximately 53.7 percent for each postal area. However, the forecast of 33,525 events erred from the 33,511 observed events in the CFA's jurisdiction by less than 1 percent. Because of this low error for incidents across the state of Victoria based on the most accurate year of CFA incident information collection, we concluded that this linear model was suitable for forecasting future incidents.

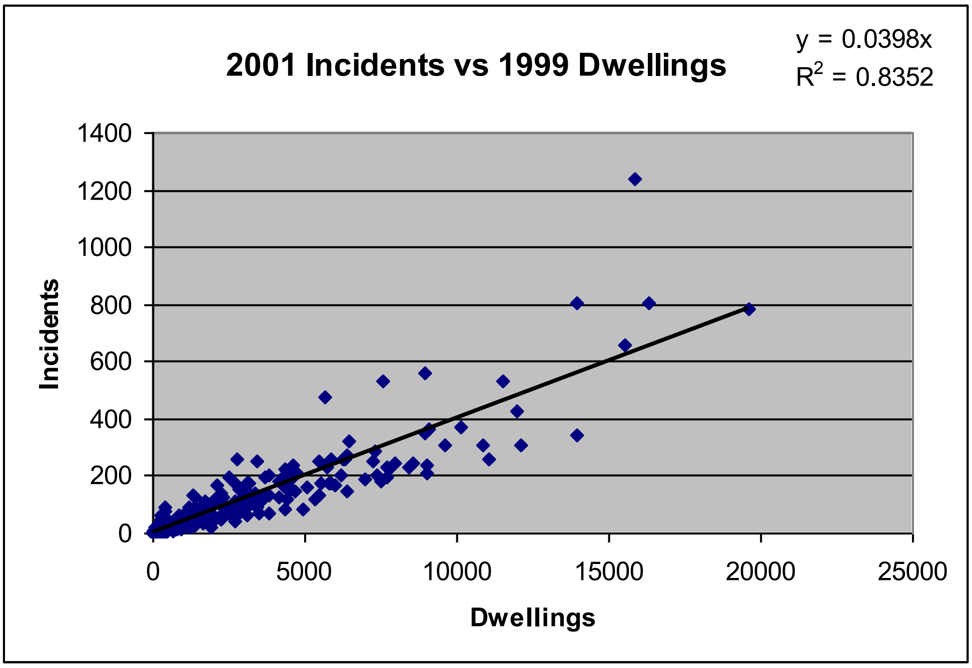


Figure 7. 2001 Incidents vs Estimated 1999 Dwellings for POAs

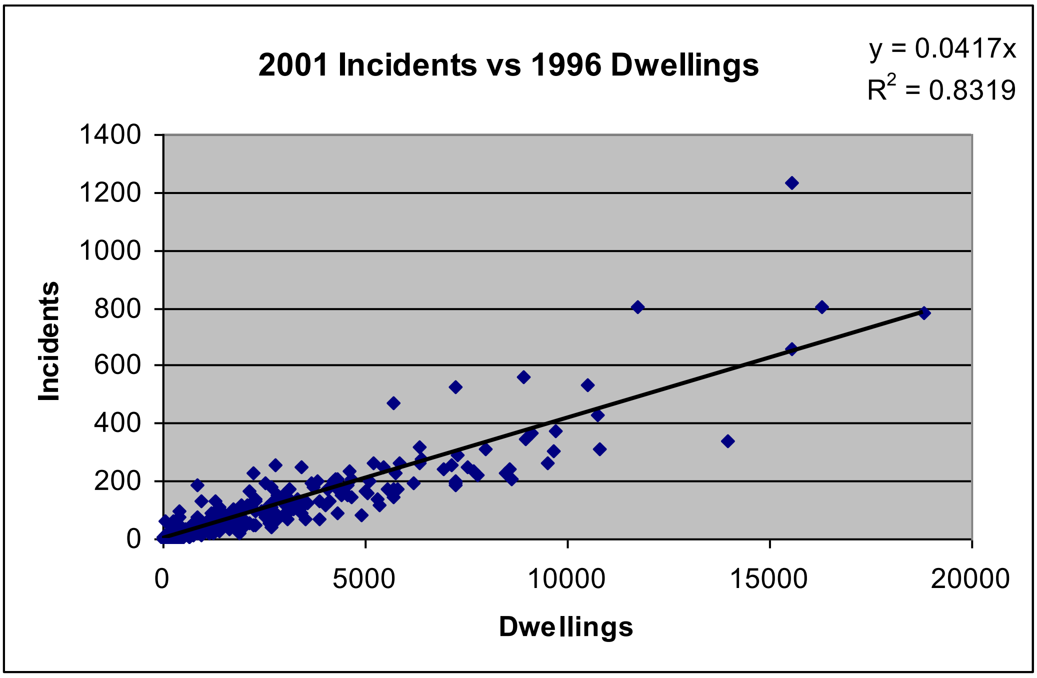


Figure 8. 2001 Incidents vs 1996 Dwellings for POAs

Incident Forecasting

We used the linear regression model to predict the increase in CFA incidents due to residential development. Adding the Department of Infrastructure residential development forecasts to the estimated dwellings existing in 1999, we produced dwelling projections for POAs in the CFA's jurisdiction for 2004 and 2009. We based these forecasts on the intended dwelling capacity of land releases forecasted to be developed in five-year increments, beginning in 1999. The development of land releases zoned for residential development beyond 2010 cannot be determined because development depends on future economic and political conditions whose behaviour was beyond the scope of this project. Residential land releases whose time of development the DOI could not forecast were not included in the dwelling projections were considered separately. We used the linear regression model to produce a prediction of the number of CFA incidents in Victoria based on the dwelling projections. This model showed an increase in CFA incidents and is discussed in the following section.

The output from applying the regression model to the state of Victoria is depicted in Table 6. The incidents were estimated for the year following the residential development forecasts and were based on the estimated number of completed dwellings at the beginning of the calendar year.

Table 6. CFA Incident Forecasts

Year	Incidents	Percent Increase (from 2001)
2001	33511	0
2005	35185	5.00
2010	36620	9.28
2011+	45338	35.29
Non-forecast	45917	37.02

The model predicted an incident increase of 5 percent from 2001 to 2005 due to new dwelling development. This corresponds to a yearly increase of 1.23 percent over the four year period. This rate of incident increase was projected to decrease slightly to 0.80 percent per year for the following five years, totalling a 9 percent incident increase in nine years (See Figure 9).

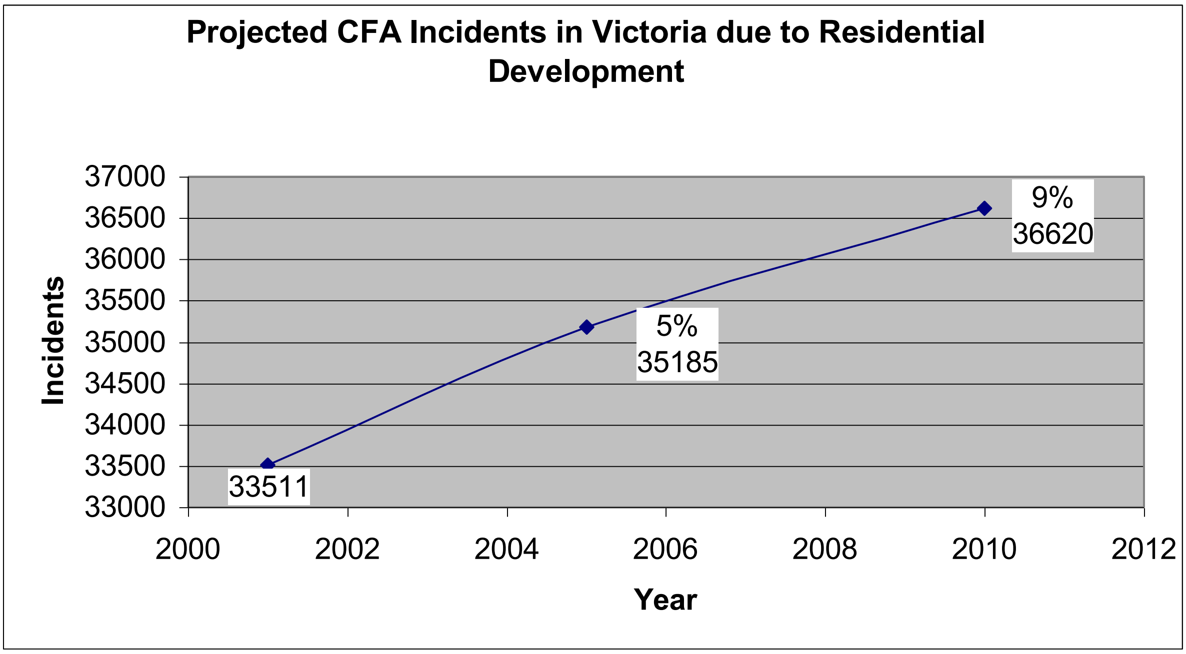


Figure 9. Projected Incidents due to Development Through 2010

This 9 percent corresponds to an increase of 3,109 incidents. Beyond 2010, the incidents will continue to escalate due to dwelling development, although the rate cannot be conclusively predicted. When all of the residential development forecasted by the 1999 DOI publication is completed, the CFA, under current conditions, is projected to respond to 45,917 incidents per year, 37 percent more than the 33,511 incidents in 2001. The majority of this increase is expected to occur after 2010. The relative contributions of the timing classifications to the increase in incidents is depicted in Figure 10.

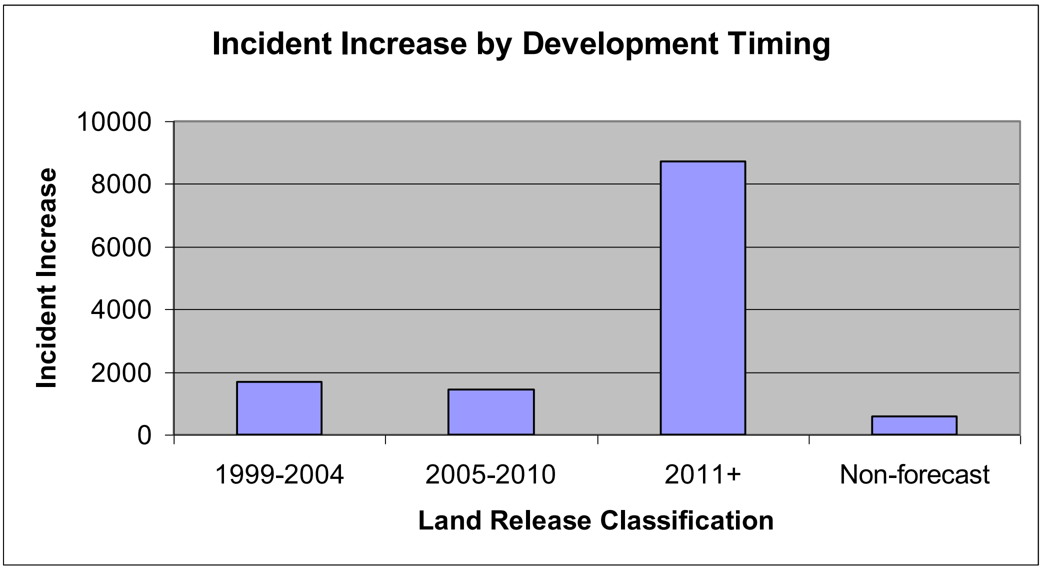


Figure 10. Incident Increase by Land Release Development Timing

Although the forecasted percent increase in incidents of 4 percent between 2005 and 2011 is slightly less than the 5 percent forecasted for the previous four years, we cannot speculate that this trend will continue beyond 2010 because of the volatility of the housing development market. Should the dwellings forecasted for long-term development be completed by 2015, the increase in incidents would be dangerously high (See Figure 11). In this worst-case projection, the period from 2011 through 2015, would experience a yearly percent increase of 4.36 percent. However, if the yearly increase in events remains around 1 percent, Victoria will not experience 45,000 events until 2030 (See Figure 12). In reality, the long-term rate of increase in CFA incidents due to residential development will most likely be between 1 percent per year and 4 percent per year. All of the long-term development sites will not be completed within five years; however, the Department of Infrastructure has indicated that its dwelling projections have underestimated the most recent development, indicating that the 1 percent incident increase errs on the low side.

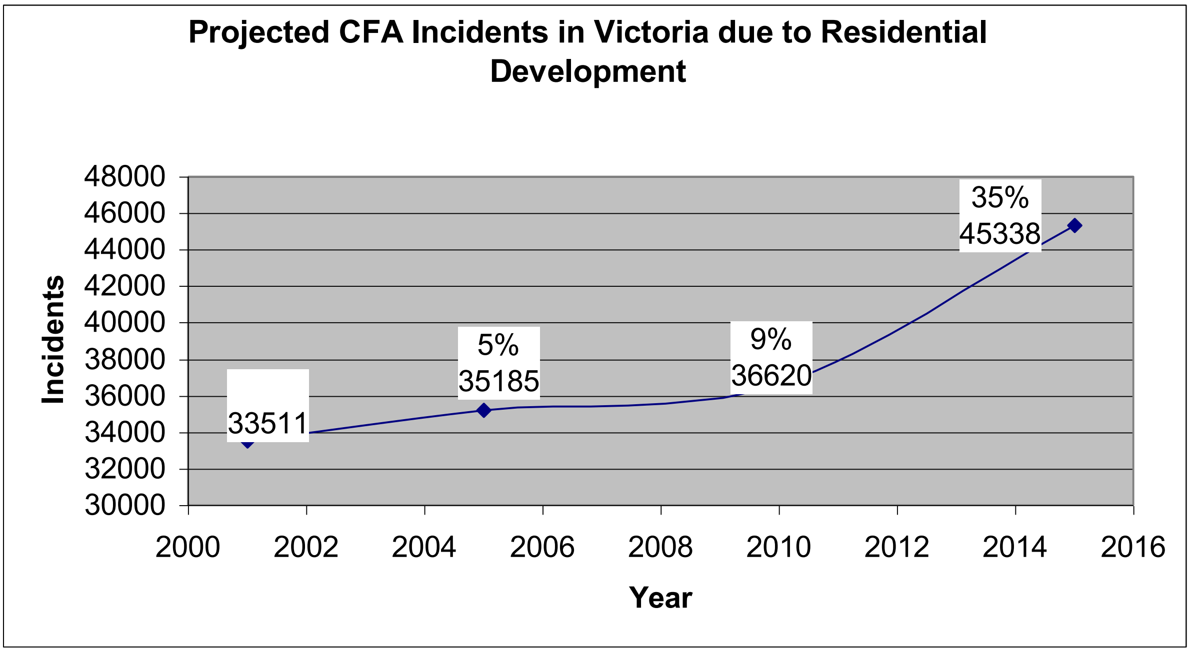


Figure 11. Projected CFA Incidents due to Development – Worst Case

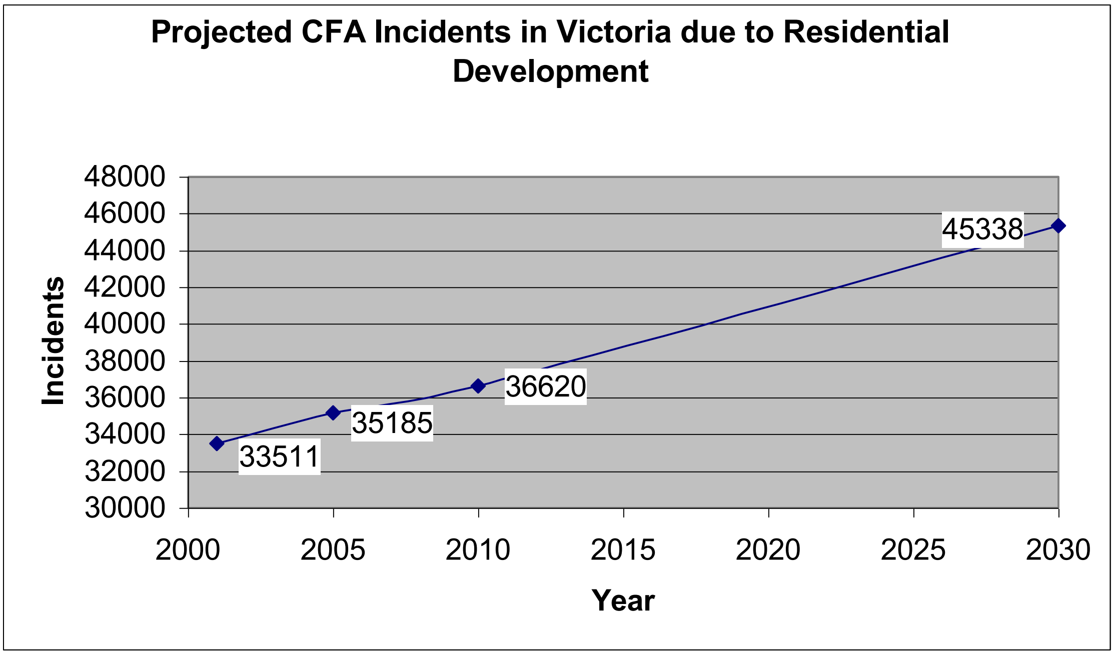


Figure 12. Projected CFA Incidents due to Development - Steady Increase

Although a 1 percent yearly increase in incidents seems modest, the concentration of the growth corridors in the Melbourne region amplifies the threat. Because the CFA incidents are related to the number of dwellings, the residential development in the POAs surrounding Melbourne corresponds to the regions that will experience the increased incidents. The ten POAs projected to experience the greatest increase in incidents account for 9,380 of the 12,406 incident increase predicted if all forecasted residential developments are completed. These POAs are all located in the greater Melbourne area. For example, POA 3030 (See Figure 13) is forecasted to encounter 2,756 more incidents per year upon completion of all projected developments, a 342 percent increase. This increase is primarily because of long-term development, with little short-term threat. By 2010, the POA 3030 annual incident rate will have increased by only fifty-one incidents per year, from 806 to 857 incidents per year. Also, the model forecasts a decrease in annual incidents in 2005, down to 704.

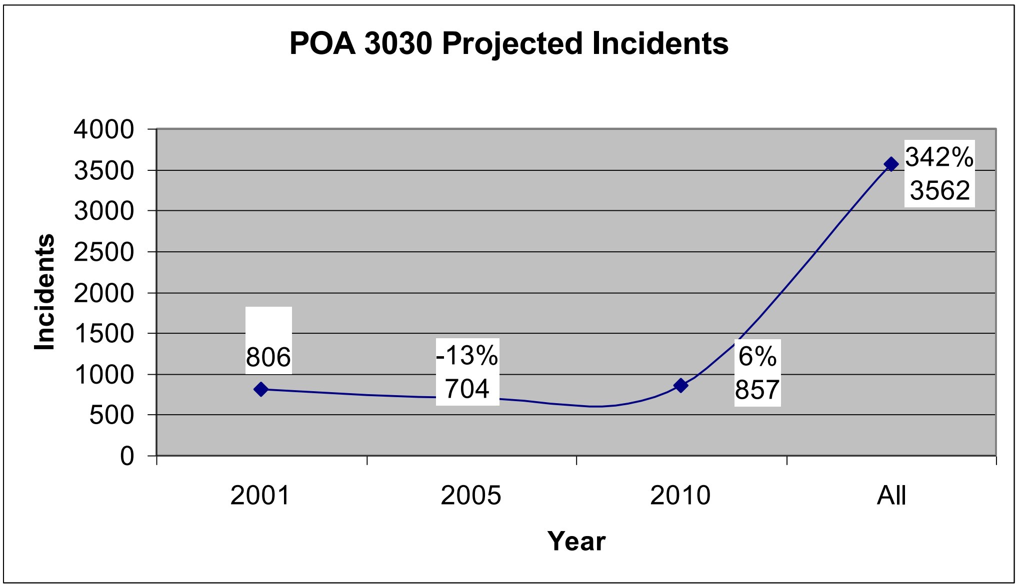


Figure 13. POA 3030 Projected Incidents

POA 3037 has a more imminent danger. POA 3037 (See Figure 14) is projected to increase from the 185 incidents reported in 2001 to 392 incidents in 2005 and 627 incidents in 2010, a 239 percent increase in nine years. This corresponds to a 21 percent yearly increase in incidents through 2005. Furthermore, applying the model to estimate the 2001 incidents actually underestimates the observed incidents for this POA by 4.55 percent. If the forecasts also underestimate incidents, the increase may be more severe than the future projections indicate.

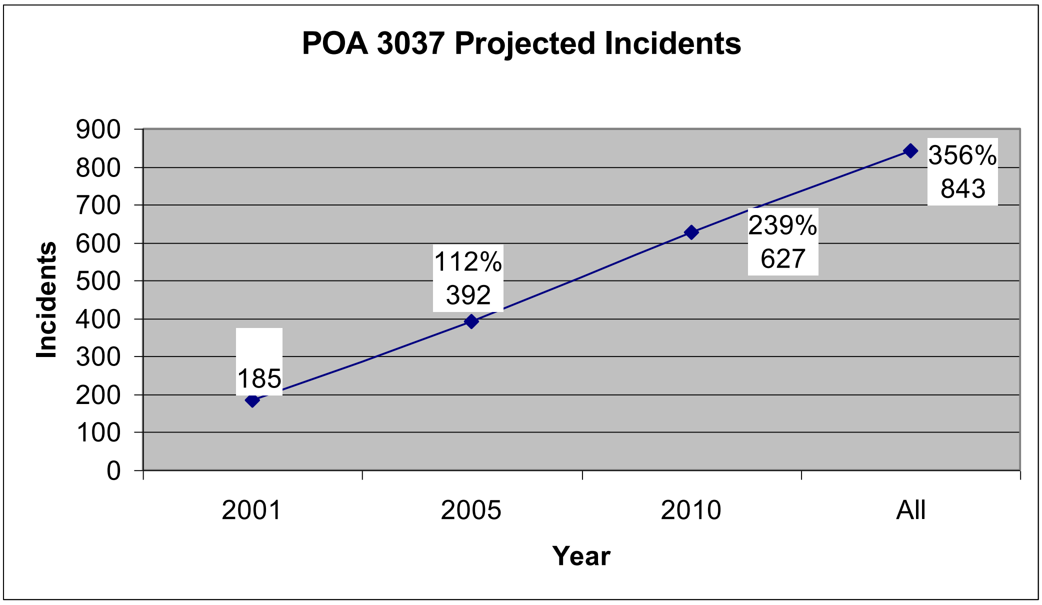


Figure 14. POA 3037 Projected Incidents

The POAs having the greatest forecasted incident increase are listed in Table 7 through Table 9. Table 7 depicts the fifteen POAs having the greatest short-term increases in incidents. Similarly, Table 8 lists the POAs having the greatest medium-term incident increases, and Table 9 shows the greatest long-term increases. Map 5 through Map 7 spatially display the short, medium, and long-term threats in the Melbourne region. The long-term threat forecast is especially foreboding. Two POAs are estimated to incur an increase of more than one thousand incidents per year. An increase of this magnitude in a single POA will drastically effect the operations of the fire brigades responsible for these regions. The threat forecast maps, along with the databases containing the incident increase projections, are now stored on the GIS Services' computer system.

Table 7. High Risk POAs – Short-Term

POA Label	Incidents 2001	Projected Incidents 2005	Incident Increase	Percent Increase from 2001
3805	311	645	334	107.38
3037	185	392	207	111.66
3195	211	400	189	89.71
3029	261	446	185	70.96
3976	149	296	147	98.61
3806	168	297	129	77.00
3095	240	367	127	52.88
3802	185	312	127	68.58
3174	310	433	123	39.70
3196	196	316	120	61.09
3429	248	366	118	47.48
3931	192	308	116	60.41
3400	82	195	113	138.08
3690	229	336	107	46.67
3156	430	526	96	22.37

Table 8. High Risk POAs – Medium-Term

POA Label	Incidents 2001	Projected Incidents 2010	Incident Increase	Percent Increase from 2001
3037	185	627	442	238.84
3805	311	751	440	141.37
3977	534	746	212	39.70
3195	211	420	209	99.00
3029	261	455	194	74.28
3976	149	324	175	117.38
3806	168	338	170	101.49
3429	248	396	148	59.54
3059	227	365	138	60.84
3931	192	320	128	66.85
3095	240	367	127	53.11
3802	185	312	127	68.58
3174	310	433	123	39.70
3196	196	316	120	61.09
3400	82	195	113	138.08

Table 9. High Risk POAs – Long-Term

POA Label	Incidents 2001	Projected Incidents (all)	Incident Increase	Percent Increase from 2001
3030	806	3562	2756	341.95
3064	262	2109	1847	704.79
3337	529	1502	973	183.98
3977	534	1273	739	138.36
3037	185	843	658	355.64
3429	248	780	532	214.35
3975	59	589	530	897.54
3752	129	645	516	399.72
3805	311	753	442	142.26
3810	206	594	388	188.33
3809	31	403	372	1200.60
3757	119	452	333	280.14
3059	227	524	297	131.02
3195	211	420	209	99.00
3029	261	459	198	75.89

As noted in the previous chapter, the model had an average error of 54 percent, corresponding to an error of twenty-one incidents for each POA prediction in 2001. For the postal areas with a high number of incidents, this error is insignificant. However, the average percent error for postal areas of 54 percent represents a considerable number of incidents for the high risk POAs. Thus, the accuracy of the model depends on the criteria. To better understand the precision of the model for the high risk POAs, we determined the model's error for POAs that recorded more than one hundred incidents in 2001. The 2001 modelled incidents for these POAs had an average error of sixty-five incidents, which corresponded to only 27.2 percent error. A 27.2 percent error is still significant, but allows us to forecast incident increases in high risk areas. A 27 percent error pales in comparison to the high incident increases projected, many of which are well over 100 percent.

The accuracy of the model also depends on the accuracy of the DOI's residential development forecasts. Currently, development is exceeding projections. The volatility of the housing market, however, makes long-term development projections precarious. Ultimately, residential development and the corresponding increase in incidents depend heavily on socio-political factors such as interest rates, government policy, and social trends. Consideration of these factors is outside the scope of this project. Including socio-political elements in the modelling process requires advanced modelling techniques, such as system dynamics. Although the model produced by this project does not account for economic, social, and political influences, the model can be updated as new DOI residential development data is released.

Updating the model with new FIRS incident data will improve the accuracy of the model, as well. Use of the FIRS system increased steadily from 1999 to 2001, and future years will likely contain more accurate representations of the CFA's incidents. Furthermore, comparing the future incident records to the forecasts of the model will help identify strengths and weaknesses and improve future modelling.

Chapter 6. Recommendations

Recommendation 1. We recommend that the CFA consider the impact of the forecasted increase in emergency incidents. The forecasted incident increase in the surrounding areas of Melbourne have the potential to place a strain on the CFA assets in these regions. We advise that the CFA examine their resources and work load capabilities in the high risk POAs.

These postal areas of elevated risk can be further analysed by researching items such as accessibility to water supplies, the abilities of local brigades to respond to various types of incidents, and the ability for brigades to achieve satisfactory response times factoring in the suburban expansion. There are numerous other factors that may contribute to the changing incident activity and a proper analysis of these factors will enable the CFA to better manage the forecasted increase in events.

Recommendation 2. We recommend that the CFA become more involved with growth planning. Instead of reacting to the changing incident patterns across Victoria, the CFA could help manage the frequency of incidents by becoming involved with development planning at the local level. Local councils determine growth policy and make decisions on zoning land parcels. The CFA can influence local development planning or advise councils on the fire protection issues pertinent to residential development in order to minimise incident increases in high threat regions.

Recommendation 3. We recommend that the CFA continue efforts to model incidents using dwelling information with an emphasis on modelling at the local level. Through the statistical analyses conducted on the spatial relations between Victoria's dwelling information and the CFA's FIRS data, we were able to create a linear model with the abilities to forecast future CFA incidents. Despite the fact that this model had the ability to forecast the number of incidents across the state of Victoria with a narrow margin of error, it achieved less accuracy when forecasting CFA incidents on a smaller level, such as census collection districts. However, accurate forecasting on a smaller scale has the potential to provide the CFA with particularly useful information. The appeal of incident forecasting with an increased accuracy develops the foundation for this recommendation.

We advise the CFA to continue the correlation analysis between Victoria's dwelling density and FIRS incidents by conducting this analysis on the municipal level rather than on the state level. By narrowing the scope of the analysis, the products of the model will be more accurate and hold greater meaning for the local municipalities. Although this modelling process is much more complicated, the localized models will better lend themselves to incident prediction over a smaller area and dependable financial budgeting for the individual brigades.

The development of local incident forecasting models will greatly improve the reliability of the models' predictions because of their ability to eliminate Victoria's demographic diversity. When viewing the distribution of dwelling density across the state of Victoria, it is evident that a large percentage of the state is covered by very low dwelling densities while small pockets of land surrounding Melbourne are contain very high dwelling densities. One of the difficulties with the state wide model was the averaging of large areas of low dwelling density with small areas of high dwelling density. Developing a forecasting model for each municipality allows the analysis of a smaller range of demographics which will lead to increased forecasting accuracy due to reduced levels of averaging.

In addition to enhancing the accuracy of the incident predictions, the use of localized models will be better suited for developing financial plans for the individual brigades. By developing a specific model for each municipality, the model will have the ability to incorporate details specific to each brigade within a municipality. These details could include information such as the history of a brigade's performance, a brigade's available resources, and the incident response capabilities of the particular brigades. The inclusion of this type of information into an incident forecasting model will greatly increase the validity of any financial planning based on an incident forecasting model. Also, the development of multiple local models will reduce the burdens of spatially allocating changes in brigade budgets. With the current model, the incident predictions are most accurate at the state level and the accuracy decreases as smaller land divisions such as municipalities are examined. This induces a complexity when attempting to examine resource needs for individual brigades from an incident prediction that originates from a state wide model. Localized models will have a direct connection to local brigades, easing the complexities involved in assessing the adequacy of brigade resources.

Recommendation 4. We recommend that the CFA, especially the GIS Services department, and the land and development information department of the Department of Infrastructure establish a formal mode of communication between each other. In the process of developing this model, we conducted an extensive examination of the Department of Infrastructure's land development forecasts. Through this examination we obtained a profusion of information about the Department of Infrastructure's capabilities and forecasting process. We believe that the CFA has the potential to benefit greatly from the Department of Infrastructure's knowledge about Victoria's land development issues.

It is of our understanding that informal communication modes between the GIS Services department and the Department of Infrastructure do exist but do not utilize the full potential of the Department of Infrastructure's knowledgebase. By opening new communication channels between the CFA and the Department of Infrastructure, the CFA will be able to receive expert interpretations of development databases and will develop a firm understanding of how the Department of Infrastructure collects its data and develops its forecasts. This understanding will allow the CFA to interpret their own analysis results with an enhanced level of accuracy. Also, the Department of Infrastructure publishes new development forecasts every two years. Through communication, the CFA could receive updates on dwelling forecasts to supplement the biannual publications.

Also, the Department of Infrastructure develops a forecasting system which produces accurate results on a municipal level. The products of these land development forecasts on the municipal level would be very useful to the development of localized incident forecasting models. Due to the fact that the Department of Infrastructure already has accurate dwelling information on the municipal level, the process of creating localized incident forecasting models would be relatively straight forward.

Recommendation 5. We recommend that the CFA apply system dynamics to further investigate the relationships between Victoria's demographic factors and the occurrence of CFA incidents. There exist other modelling techniques that have the ability to better forecast CFA involved incidents.

System dynamics offers a unique modelling solution to CFA incident forecasting. System dynamics is a computer-based modelling process that investigates the interconnectivity of different variables to identify the dynamics of a particular system. In the case of the CFA, system dynamics can be used to determine the occurrence of incidents over a period of time given the relationships between variables such as urban sprawl, CFA resources, vegetation densities, and climate. Implementing a system dynamics model will also lead to the discovery of nonlinear relationships between variables which may have gone unnoticed in previous correlation analyses.

Ultimately, a system dynamics model can be used to develop a model of fire cover for the CFA in which different policies can be simulated before they are implemented. When a system dynamics model is constructed, its versatility allows the user to change the values of different variables, such as vegetation growth or residential land development. Once these values are altered, the model can be used simulate actual conditions given the values of the altered variables. The ability for system dynamics to run simulations of actual conditions enables policies to be tested on a simulator, the system dynamics model, before they are implemented in the real system.

We feel that system dynamics offers the best solution for modelling fire cover within the state of Victoria. System dynamics is a robust modelling process that can effectively simulate real systems and easily uncover problem areas within the modelled system. Although system dynamics modelling is a highly involved process, the rewards of an effective model can be extremely beneficial. For an in depth discussion of systems dynamics, how it works, and the societal impacts of a system dynamics model, refer to Appendix B.

Appendix A: Sponsor Overview

The Country Fire Authority (CFA) provides fire-fighting, fire suppression, fire prevention, and emergency services to the entire state of Victoria, excluding metropolitan Melbourne, national parks, and state forests. To accomplish the CFA's mission, "to provide a cost effective fire and emergency service for the people of Victoria," the umbrella organization facilitates cooperation and management of community fire brigades, ensures training for its members, and actively promotes fire safety awareness (CFA, 2001b). In addition, the CFA creates an extensive support network for community fire brigades and a unified central administration.

The development of the CFA corresponds to Victoria's history of devastating brush fires (CFA, 2001b). The CFA's authority and responsibility grew through a series of legislation, beginning with the Fire Brigades Act of 1890 that created a Country Fire Brigades Board. The CFA itself was established following serious fires in 1926, 1939, and 1944. With support from both the government and the communities of Victoria, the CFA has evolved into one of the largest volunteer-based fire-fighting institutions in the world (CFA, 2001b).

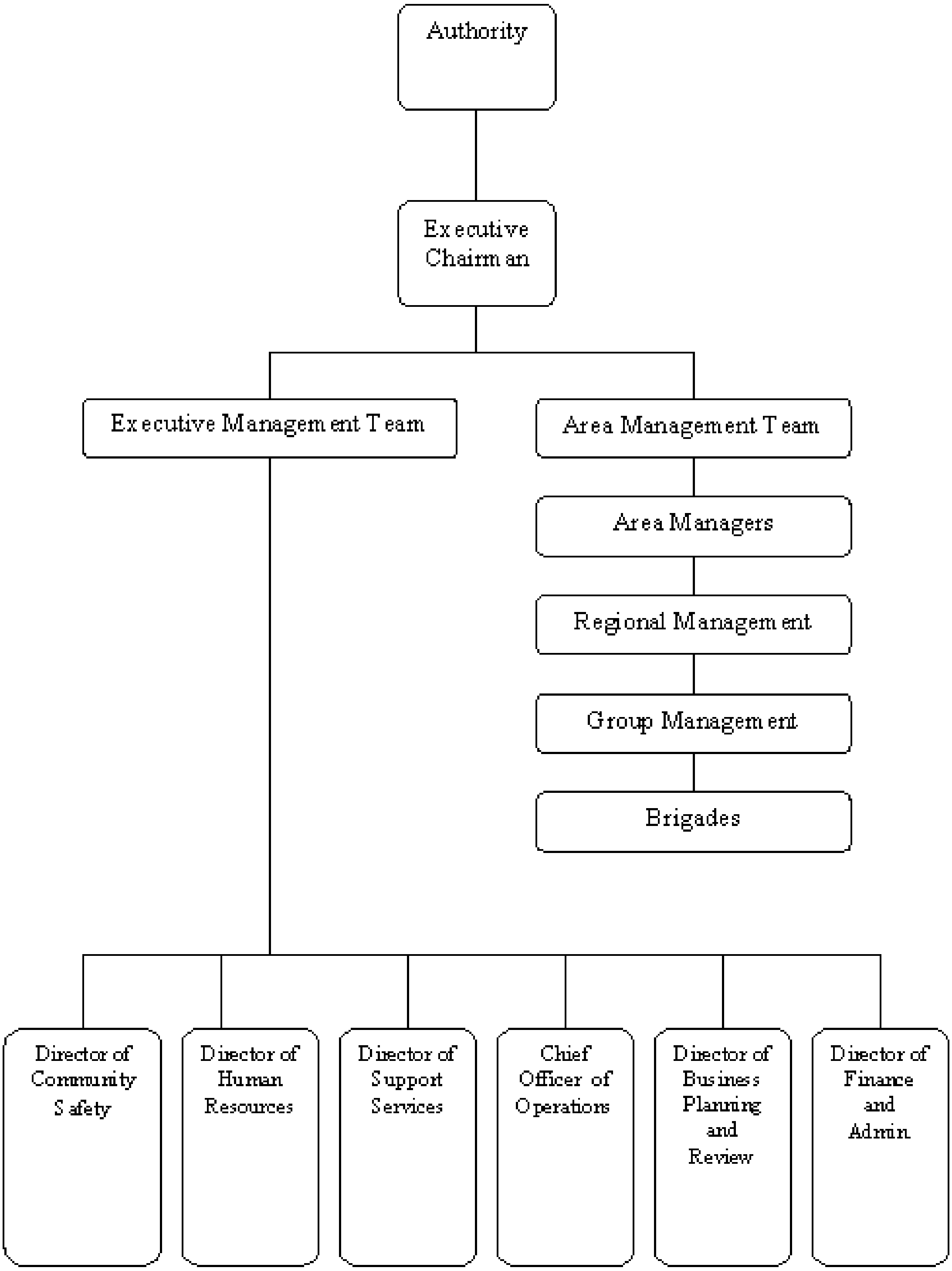
Heading the CFA is the Authority, a twelve-member board that reports to Victorian Government's Minister for Police and Emergency Services (See Figure 15). The Chief Executive Officer serves a liaison between the Authority, the Executive Management Team, and the Area Management Team. In addition, the Chief Executive Officer handles legal responsibilities and official communications. The Executive Management team oversees the various responsibilities of the central administration. Each team member is responsible for management and coordination of a specific function. These specialties are community safety, human resources, support services, operations, planning and review, and finance and administration.

Eleven area managers comprise the Area Management Team. These managers represent their respective jurisdictions, ensuring fire-fighting units are properly equipped. The eleven areas are further subdivided into twenty regions. At the regional level, committees plan general fire control strategies. One hundred forty-three groups are defined within these regions to facilitate direct coordination between neighbouring fire brigades. These 1,228 brigades form the operational arm of the CFA's fire safety operations. Brigades are responsible for community-level fire planning, community fire education, training, and fire response.

As a member of the Executive Management Board, Neil Bibby, the Director of Community Safety, oversees risk assessment and risk communication to the community (See Figure 16). To educate the public on fire safety, the Director of Community Safety also manages community outreach safety awareness programs. Towards this goal, the CFA is continually developing new methods to communicate fire risk to the public.

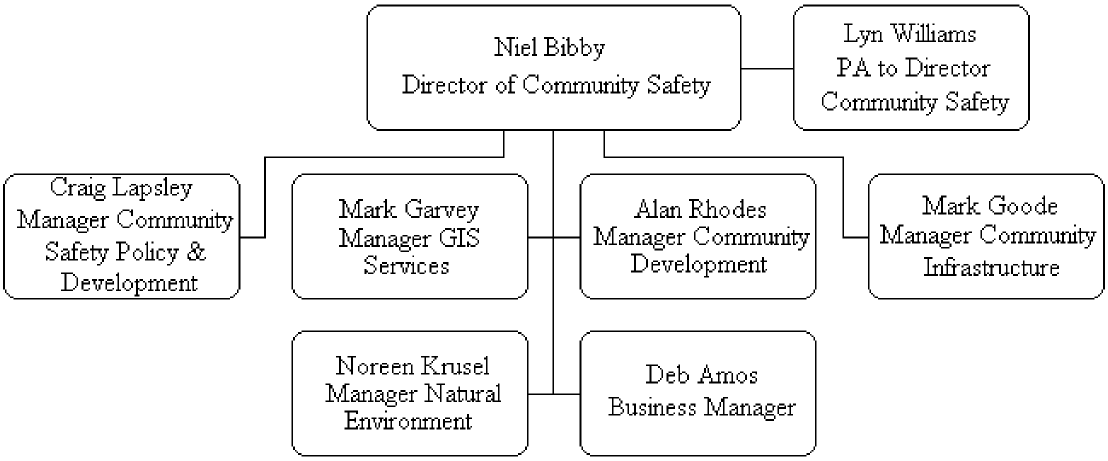
The GIS Services program in the Community Safety branch performs data collection and analysis with Geographical Information Systems and develops tools to plan a safer community. Operating under Mr. Mark Garvey, the GIS Services department (See Figure 17) provides spatial information to various departments throughout the CFA, providing current information to assist emergency service planning and response. The lack of products combining GIS technology with fire service functionalities requires the GIS Services department to research and develop avant-garde systems for the CFA. These systems range from road speed classification methods for transportation network modelling to predictive fire risk modelling for infrastructure planning. The liaison in the CFA for this project is Mr. Ron Shamir, the statistical analysis specialist for the nine-member GIS Services team.

Figure 15. CFA Organisational Structure



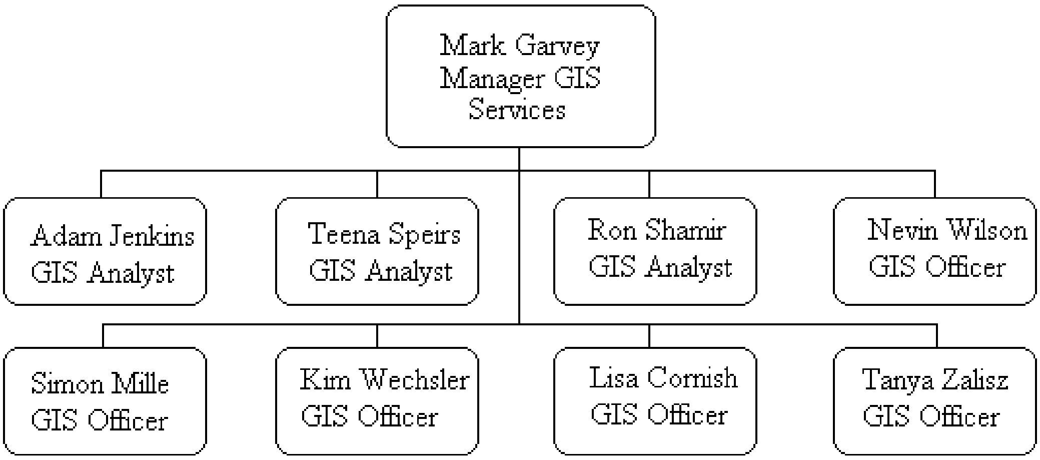
Adapted from The Fire Wire, Country Fire Authority, 2001.

Figure 16. Community Safety Organizational Structure



Adapted from <u>The Fire Wire,</u> Country Fire Authority, 2001.

Figure 17. GIS Organizational Structure



Adapted from <u>The Fire Wire,</u> Country Fire Authority, 2001.

Appendix B: System Dynamics Overview

When analysing large, complex systems such as the fire threat across Victoria, Australia, it is important to identify and understand the major contributing factors that comprise and influence the system. A solid understanding of these factors will allow for an accurate and comprehensive analysis of these systems. In the case of the fire threat across Victoria, there are numerous elements that formulate fire risk. These elements range from structure proximity to vegetation to residential development trends. Dynamic systems, such as the fire risk in Victoria, contain many interrelated variables that must be considered during a proper analysis of the system.

Currently, the Country Fire Authority is investigating the fire risk across the state of Victoria to conform to the recently published Australian/New Zealand risk management standard, AS/NZS 4360:1999. In accordance with their analysis of fire risk, the CFA is developing a model of fire cover for Victoria to enable equitable fire service coverage across the state. This model of fire cover consists of GIS studies and statistical analyses of demographics, economic factors, and CFA incident history, which will assist the CFA with future resource allocation. Although these GIS and statistical analyses have the ability to determine certain relationships existing between spatial data specific to Victoria and the CFA's incident history, they do not account for the interrelationships existing between most of the factors influencing Victoria's fire risk. Often, these interrelationships are cyclical, forming feedback loops throughout a system. The incorporation of these feedback loops and interactions between the major variables that influence fire risk will allow for the development of a model that will be able to accurately display and predict the behaviour of the fire risk in Victoria.

In order to supplement the CFA's GIS and statistical analyses of the fire risk in Victoria, the application of system dynamics will provide a more comprehensive analysis of the elements influencing the fire risk in Victoria. System dynamics is a method for modelling complex systems and problems using computer simulations to help derive an understanding of the system being modelled (Radzicki 1997). The application of system dynamics to the CFA's model of fire cover will allow the CFA to project the dynamic behaviour of fire risk rather than react to historical data through regression analyses based on the correlation of a few variables. System dynamics will also allow the CFA to understand how the fire risk in Victoria will change over long periods, potentially assisting with the perpetual resource allocation process.

Brief System Dynamics History

The field of system dynamics modelling originated from Massachusetts Institute of Technology (MIT) in the 1950s and was developed by Professor Jay Forrester. Forrester began his academic career as an electrical engineer, working on many projects at MIT, ranging from naval servomechanisms and feedback control systems to advanced computer systems. These projects included MIT's first digital computer system Whirlwind I and the Semi-Automatic Ground Environment (SAGE) computer system, which were used for air defence (Forrester, 1989). In 1956, Forrester's academic focus switched from electrical engineering feedback systems to management when he became a professor in MIT's newly developed business school. A career in management was not a drastic change for Forrester because he was already managing multiple billion-dollar research operations. His management experience consisted of writing contracts, and managing research endeavours with his colleagues for the Air Defence Command, AT&T, and other major corporations (Forrester, 1989).

The development of system dynamics was initiated when Forrester learned of a predicament that a General Electric appliance plant in Kentucky was facing in the late 1950s (Forrester, 1989). This General Electric plant was struggling with fluctuations in their workforce. General Electric assumed the fluctuations were a product of a natural three-year business cycle. Subsequent to researching the context of the problem, Forrester created a simplistic model of the General Electric plant's management processes. By mapping the interrelations between the major variables, such as inventory levels and production rates, Forrester was able to determine that the fluctuating workforce emanated from internal policy rather than the three-year business cycle. Through the creation of Forrester's model, the employment instability problem was rectified and the field of system dynamics was born (Forrester, 1989).

As time progressed, Forrester continued to develop the field of system dynamics. Forrester's next undertaking was the development of the Urban Dynamics model that examined the socio-economic decline of Boston, Massachusetts in the late 1960s (Forrester, 1989). Forrester worked with John Collins, a former mayor of Boston, to develop a system dynamics model for Boston. The model produced results that seemed outrageous at the time to many politicians and residents of Boston. The model suggested that the removal of low income housing from Boston would bring social and economic revitalization to the city. Shortly after the publication of the results, a member of New York City's government confirmed Forrester's findings (Forrester 1989).

Forrester continued his career developing other major models, which received significant public interest. These models included the National Model, World

Dynamics, and Limits to Growth (Forrester, 1989). World Dynamics and Limits to Growth received enormous amounts of public attention because they discussed the future of our planet and the limitations of our natural resources.

System Dynamics Theory

Currently, system dynamics is an emerging field in the social sciences that has the ability to model and simulate real world systems such as business and economic cycles. System dynamics differs from typical modelling processes by allowing the incorporation of not only measured and numerical data, but also mental information into a highly insightful representation of the actual system. The incorporation of mental data segregates system dynamics from ordinary modelling techniques (Forrester, 1991). Mental data is described as information that is acquired through experience and understanding of system interrelations. In the field of system dynamics, mental data is used to distinguish and identify how certain variables in a system affect each other and how they are related. Modelling done in system dynamics is useful and effective because it builds on the reliable part of our understanding of systems while at the same time compensating for the unreliable part (Forrester, 1991).

In order to start building a system dynamics model, it is necessary to have a clear understanding of both informal and formal models. Formal models such as regression studies allow enhanced understanding by simplifying certain aspects of the entire system (Radzicki 1997). Formal models give a much better understanding of how a system actually works and how components of the model interrelate to other components in the system. Formal models are typically constructed upon measured or numerical data, which allows for the development of equations. These equations represent the relations between variables. Informal models, or mental models, are more flexible, detailed, and are typically constructed from experience (Radzicki 1997). However, since informal models are usually constructed from brainstorming sessions, they may be incomplete and may not fully depict the relations within a system. Also, many assumptions included in informal models are made without adequate research.

System dynamics bridges the gap between formal and informal models by incorporating the information from both types of models. This blending of models is accomplished by mapping out mental models on computers and allowing the computer to trace through the dynamics of the modelled system (Radzicki 1997). Computer simulation allows system dynamics to incorporate the numerical data typically found in formal models with the subjective, but highly important, experience based information from informal models. The combination of these two models in the system dynamics modelling process allows for the construction of highly complex models.

Detailed information gathering is essential for an accurate model. Researching the system of interest will allow the structure and the behaviour of the system to be understood on a basic level. When developing a system dynamics model, it is important to completely understand the system of interest. A comprehensive knowledge of the system in question and the policies that govern this system will enhance the accuracy of the model (Forrester, 1991). The establishment of clear objectives and comprehensive knowledge of the system will lead to a successful system dynamics inquiry (Forrester, 1991). The success of a system dynamics study can be defined on multiple levels. Mainly, success is achieved through confirmation that the system dynamics model accurately represents the system in question. However, true success of a system dynamics model is achieved through the alteration of the way people perceive the dynamics of this system (Forrester 1991). An example of changing system perceptions is exemplified through Forrester's Urban Dynamics model as discussed in the brief history of system dynamics section.

System Dynamics Variables

Variables incorporated in a system dynamics model are distinguished into two different types: stocks and flows. Stocks represent state variables that describe the current condition of a system, while flows represent the rates or changes within a system. Stocks can be described as accumulators which have a certain level at all times while flows are rates which alter the accumulations within the stocks by either adding or draining the contents of the stocks (Radzicki, 1997). A stock can have any number of inflows and outflows which control the contents of the stock. Examples of stock variables are population and fires because the size of population and numbers of fires are state variables. Some examples of flow type variables are urban sprawl and fire suppression. Urban sprawl and fire suppression are flows because they are rates and have the ability to change states such as population size and number of fires. In addition, stocks are not time dependant while flows are dependant upon time. If time were to stop, stocks would retain their value, while flows would become zero (Radzicki 1997). Also, in computer simulation, stocks are used to decouple flows. The breaking up of flows is completed by creating an inflows and outflows for each stock allowing the stock to be affected by multiple sources of information (Radzicki, 1997).

As part of the process in developing the field of system dynamics, Forrester incorporated the concept of feedback control loops into system dynamics models. Feedback is described as a system that has outputs that respond to and influence their inputs, meaning that they are influenced by their past behaviour (Radzicki, 1997).

Every feedback loop in a system dynamics model must contain at least on stock, or state variable. Feedback exists when the level of the stock alters a flow, which inturn modifies the stock. Feedback loops can also be classified as negative or positive. Positive feedback loops which invoke a destabilising action are rare in system dynamics modelling but do exist (Radzicki, 1997). An example of a positive feedback loop is shown in Figure 19. A negative loop, on the other hand, is described as a stabilising process that naturally tries to keep a system at a desired state. Negative feedback loops are much more abundant in system dynamics modelling that positive feed back loop and are exemplified in Figure 20.

System dynamics focuses on analysing the dynamic behaviour of a system. In other words, a system dynamics model looks at how a system behaves over time. Typically, the behaviour of each aspect in a system dynamics model is studied to see what type of behaviour pattern it exhibits. These patterns are often described in system dynamics as time shapes. There are multiple dynamic time shapes common to system dynamic models. The time shapes include linear, exponential, equilibrium, and oscillation behaviour (Radzicki, 1997). Some dynamic systems exhibit linear behaviour, although this is not typical because of the complexities of the system. Also, most system dynamics models do not exhibit linear trends because system dynamics models are able to forecast growth and reduction limits. The exponential behaviour tends to be the most common time shape discovered in system dynamics. The frequent occurrence of exponential behaviour in system dynamics is not surprising because most natural systems are found to express exponential behaviour (Radzicki, 1997). Other systems may also evince an oscillating behaviour that is either sustained, over-damped, under-damped, or randomly oscillating.

Causal Loop Diagrams

Causal loop diagramming is the most simplistic way to model a system. A causal loop diagram consists of all known factors within a system and shows how each factor interrelates to other factors (Radzicki, 1997). This is done by using feedback systems and inverse properties. Each link in a causal loop diagram has a causal interpretation. An arrow going from A to B indicates that A causes B. Causal loop diagrams can be very helpful in conceptualising and communicating structures. Many people find causal loop diagramming to be very helpful even when no simulation model exists, while others feel causal diagrams can be misleading if done in isolation. Figure 18 shows a basic causal loop diagram. The variables A, B, C, and D form a closed loop when linked. The variable at the tail of the arrow causes the changes in the variable at the head of the arrow. The change is in the same direction as the previous variable for a 'S' or '+' and in the opposite direction for a 'O' or '-'. This is known as a "cause and effect relationship." The central polarity sign indicates whether the entire loop is positive or negative. Figure 19 is a causal loop diagram that has positive feedback and expresses unstable behaviour. Other examples of positive feedback are population growth and bank panic. Negative feedback loops are more stable. An example is shown in Figure 20.

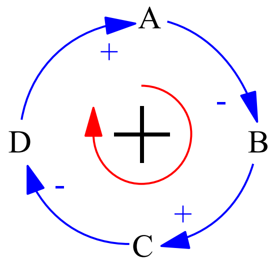


Figure 18. Basic Causal Loop Diagram

Source: Michael Radzicki, 1997

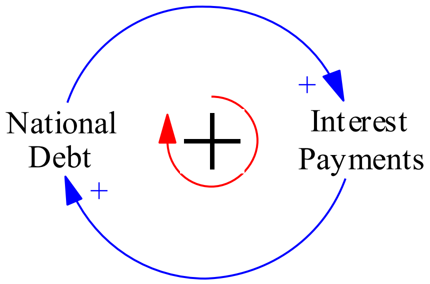


Figure 19. Positive Feedback Causal Loop

Source: Michael Radzicki, 1997

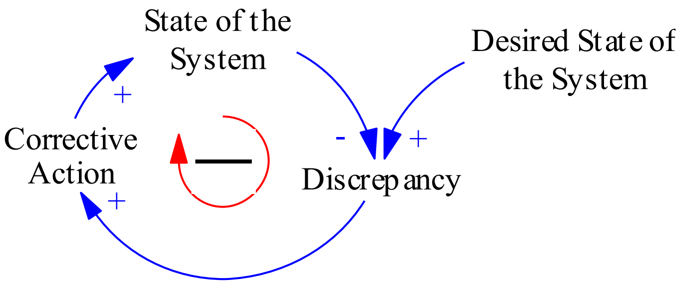


Figure 20. Negative Feedback Causal Loop

Source: Michael Radzicki, 1997

Causal loops are a good way to understand a system at the basic level. However, there are some drawbacks to causal loop diagrams. First, the variable interrelationships in causal loop diagrams are constructed through brainstorming, limiting complexity and accuracy. Thus, causal loop diagrams should not be used to determine the dynamics of a system (Radzicki, 1997). Second, they do not distinguish between stocks and flows. The construction of a causal loop diagram does not provide much insight to whether the variables are stocks or flows. Third, the dynamics of a system cannot be determined from only the polarity of variable relationships (Radzicki, 1997). The dynamics of the system cannot be directly predicted from a causal loop diagram because the complexities of the relationships between variables are not expressed in these diagrams. Due to the fact that causal loop diagrams cannot predict the dynamic behaviour of a system, they are unable to discover nonlinearities and counterintuitive behaviour which exists in many systems (Radzicki, 1997). Due to the limitations of causal loop diagrams, they should only be used as a tool for designing and developing real system dynamics models and simulations.

System Dynamics Software

SIMPLE, or Simulation of Industrial Management Problems with lots of Equations, was the first system dynamics simulation language and was developed by Richard Bennett (Radzicki, 1997). In 1959 an improved version of SIMPLE was introduced. The improved version was called DYNAMO, or dynamic models, and was developed by Phyllis Fox and Alexander Pugh (Radzicki, 1997). DYNAMO became the industry standard for thirty years and still runs today on PC compatible systems under Dos/Windows. Both SIMPLE and DYNAMO provided an equation based development environment necessary for constructing system dynamics models. These two modelling programs were the pioneers for system dynamics software modelling technology.

Vensim, a modern system dynamics modelling program, was originally developed in the mid 1980s for use in consulting projects and was made commercially available in 1992 by a company called Ventana Systems Inc. Vensim is an integrated environment for the development and analysis of system dynamics models. Vensim runs on Windows, Windows NT, and the Macintosh operating systems. An in depth description of Vensim and trial versions of the software can be obtained from http://www.vensim.com.

A competitor to Vensim, Stella was introduced in 1984 by a company called High Performance Systems. Stella provided a graphically oriented front end for the development of system dynamics models. The stock and flow diagrams used in system dynamics are directly supported with a series of tools for graphical model development. Equation writing is done through dialog boxes accessible from the stock and flow diagrams. Stella is available for both Macintosh and Windows operating systems. Additional information regarding Stella, along with trial versions of the software, can be obtained from http://www.hps-inc.com.

Advantages and Disadvantages of System Dynamics Modelling

There are many ways that system dynamics has advantages over other modelling techniques. One advantage of system dynamics is that it is intuitive and easy to understand . The use of causal loops and feedback control is easy to follow through causal loop diagramming. The development and brainstorming of the initial causal loop diagrams is rather straightforward and is based off of experience rather than from proofs of causation. Flow diagrams can also be made to better understand the causes and effects of the model. Even after a causal loop diagram has been translated into a stock and flow model, it is not an arduous task to understand the basic interactions of the system. However, as variables are added to the model, the interactions become exceptionally complex and difficult to understand. Unlike other models, such as linear modelling, which can be broken down into independent subsections and analysed individually, a system dynamics model must be analysed as a whole and cannot be divided into separate parts for analysis. Thus, it is easy to add variables and relationships, but difficult to isolate or remove individual components. In addition, highly complex models require significant commitments to keep the models current and further development.

The data requirements of a system dynamics model are less intensive than other modelling systems. The feedback relationships in the model show the dynamics of the system and how the system will change over time. A computer simulation may produce exponential growth or decay, linear behaviour, or an oscillating relationship. These are dynamic patterns rather than just a number at a specific point in time. Also, computer simulations of a system dynamics model may produce long-term projections of high accuracy and allow policy makers to better understand the implications of their policy changes. Regression based models do not have the same versatility as system dynamics models when it comes to simulation and policy testing because they can predict dynamic behaviour as well as system dynamics. The advantages and disadvantages of system dynamics in comparison to other modelling systems are shown in Table 10.

Table 10. System Dynamics' Advantages and Disadvantages

Advantages of System Dynamics	Disadvantages of System Dynamics
Less intensive data requirements	Models can become excessively complex
Relationships are based on experience, not proofs or causation	Difficult to isolate or remove subsystems
Intuitive and easy to understand	Possible to exclude important detail
Models are dynamic and include feedback relationships	Propensity to only go forward and add more complexity to solve modelling issues.
Different time shapes from simulations tell the nature of the system	Tendency to become stalemated in unending model formulation

Basic Causal Loop Diagram of CFA Incident Problems

Figure 21 is an example of a basic causal loop diagram modelling CFA incidents. It was developed using the Vensim system dynamics software package. This is a very basic model incorporating only a few system variables. An extremely accurate and precise model can take many years to develop. Model development requires substantial research to understand the effects of policies on the system in question. Usually the research is done by experts in the system dynamics field that have many years of experience and understand how to identify feedback loops and dynamic behaviour. This diagram is by no means complete. However, it should provide the reader a general understanding of how a model is developed.

The best way to understand the model in Figure 21 is to begin with the central theme: incidents in Victoria. Arrows show relationships between the ‘Incidents in Victoria’ and factors influencing or influenced by this variable. Loops are developed that show the overall system interactions. For example, starting at ‘Incidents in Victoria,’ an arrow with a plus is pointed to ‘CFA Responsibility,’ indicating that the CFA’s responsibility is directly affected by the number of incidents in Victoria. If the incidents in Victoria increase, so will the CFA’s responsibility which is signified by the plus sign near the head of the arrow. Continuing to follow that loop, if the CFA’s responsibility increases, the amount of fire prevention and suppression research will also need to increase. This will over time produce better resource allocation and thus reduce the number of incidents in Victoria, which is indicated by the arrow with negative sign pointing from ‘Resource Allocation’ to ‘Incidents in Victoria.’ There are thirty-three other loops in this model that relate other variables to incidents in Victoria.

Another way to understand the model is by looking at the causes of incidents in Victoria. Causal tracing shown in Figure 21 is a powerful tool for moving through a model and tracing the roots causes of changes. A trace can be made through the diagram looking at what causes changes in any particular variable. In this case we are looking at the causes of ‘Incidents in Victoria.’ Note that ‘Dwelling Densities’ and ‘Road Capacity’ are enclosed in parentheses and terminate the diagram before a depth of six causes is reached. The parentheses indicate that this variable appears somewhere else on the diagram, and therefore, there is a feedback loop within this particular tree diagram.

This causal loop diagram was developed by brainstorming different factors that affect incidents in Victoria and how these factors interrelate with each other. The next step would be for a system dynamics expert to study this diagram, add variables based on his observations and studies, and then convert his updated diagram into a stock and flow model. As a stock and flow model, the system can be simulated and the results of the simulations can be studied. These results would help CFA leaders make better and more informed decisions.

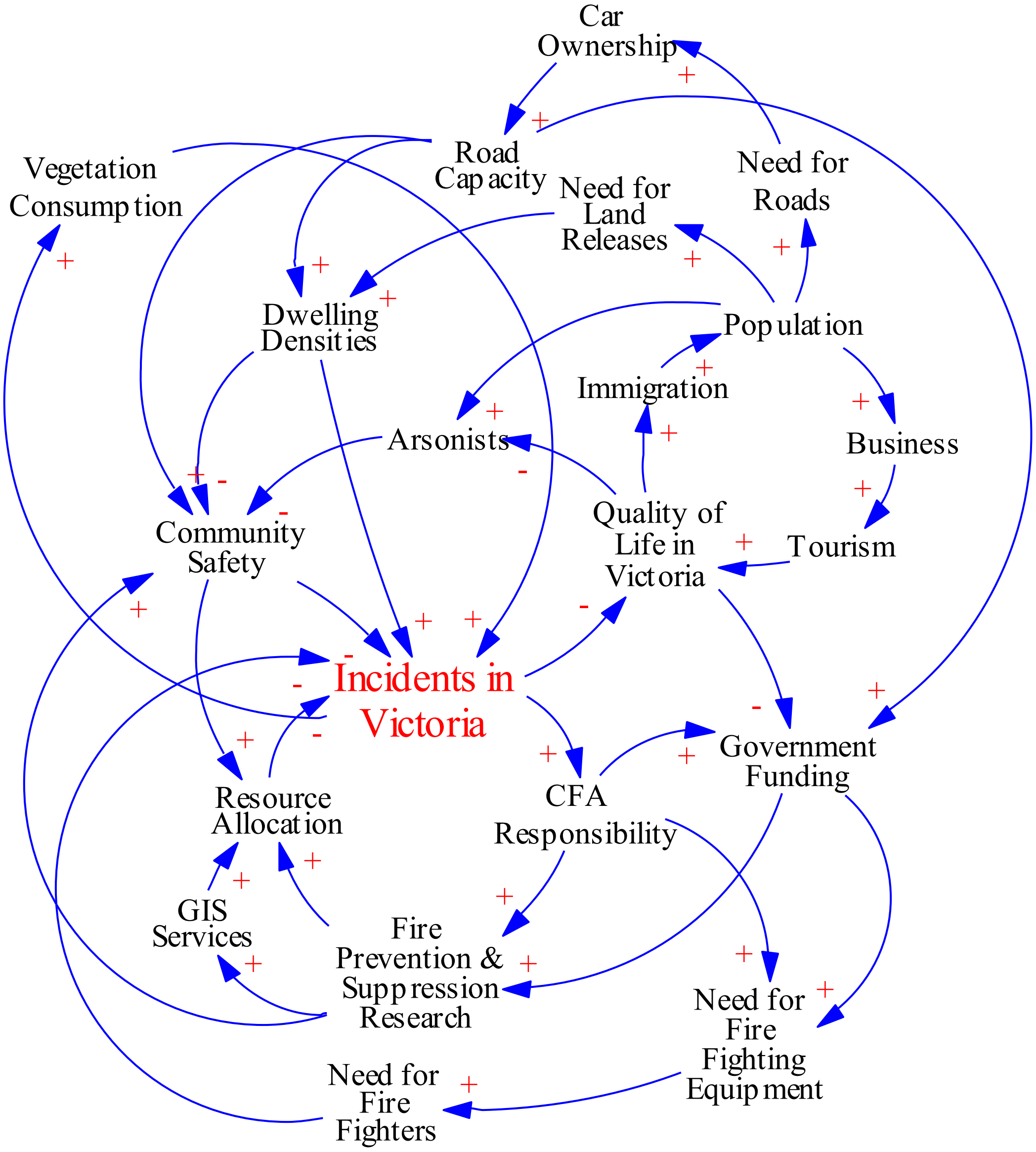


Figure 21. Basic Causal Loop Diagram Describing the CFA Incident Problem

The context of this project is summarized in the causal loop diagram depicted in Figure 22. Fire threat in Victoria is a function of many attributes, including the frequency of fire incidents and the damage caused by fire. This project established and modelled the direct relationship between residential development and the frequency of fire incidents. Through research, the CFA can develop a better understanding of this relationship and implement policies to minimize the effect of development on Victoria's fire threat. This project was the first step in that research process. This type of research is necessary to conform to the nationwide standard for threat management, which emphasizes proactive threat management in addition to the customary reactive measures. Traditional fire-fighting is merely damage control, while initiatives such as fire prevention education and involvement with local councils' development planning processes can reduce fire threat by reducing the occurrences of fire. Developing the variables and relationships depicted in Figure 22, as well as many others, into a comprehensive system dynamics model for the CFA would help clarify the fire threat in Victoria. CFA's leadership could gain a better understanding of the potential impact of proposed policy changes on the overall fire threat. Furthermore, the effects of other factors such as environmental phenomena, population growth, and urban sprawl on fire threat could be modelled to project Victoria's future fire threat, allowing CFA leadership to prepare for the state's future fire protection needs.

Figure 22. Fire Threat in Victoria

The next step in this modelling process would be to use the information contained in the casual loop diagram shown in Figure 22 to actually model the fire threat in Victoria using a system dynamics software package such as Vensim. The variables within the casual loop diagram must be categorized into either stocks or flows. Then, constants and equations must be assigned to the stocks and the flows. Once the system is modelled using system dynamics, the time shapes of each variable should be compared to the measured time shapes of the same variables in the real system. Then the modelling process becomes a continuous cycle of increasing the detail of the model and then checking to see of the model accurately represents the actual system, until the model mimics the real system.

Due to the fact that the process of constructing a real system dynamics model is an extremely involved process, we suggest that the CFA investigate the possibilities of hiring a professional system dynamics contractor to carry out this process. One local contact we discovered is Paul A. Walker.

Paul Walker works as a principal research scientist and project leader in the Commonwealth Scientific and Industrial Research Organisation, CSIRO, Sustainable Ecosystems in Canberra, Australia. Paul Walker's professional work for CSIRO has focused mainly on GIS-based modelling, but he also works as a system dynamics consultant. Paul Walker is an experienced user of Ventana's Vensim modelling software and specializes in applying system dynamics to natural resource issues. Some of Paul Walker's most recent consultancies include Training Courses on Systems Thinking and the Ventana Simulation Language, The Use of Systems Thinking – "What inhibits change in practice," and A National Land and Water Audit – Spatial data integration. The following information can be used to contact Paul Walker and to further discuss the possibilities of the use of system dynamics with in the CFA.

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34 Connungham St, Gowrie,
Canberra ACT Australia
p.walker@dwe.csiro.au
Phone: (61) 2 6242 -1697
Fax: (61) 2 6242 -1782
Fax: (61) 02 6241-3343

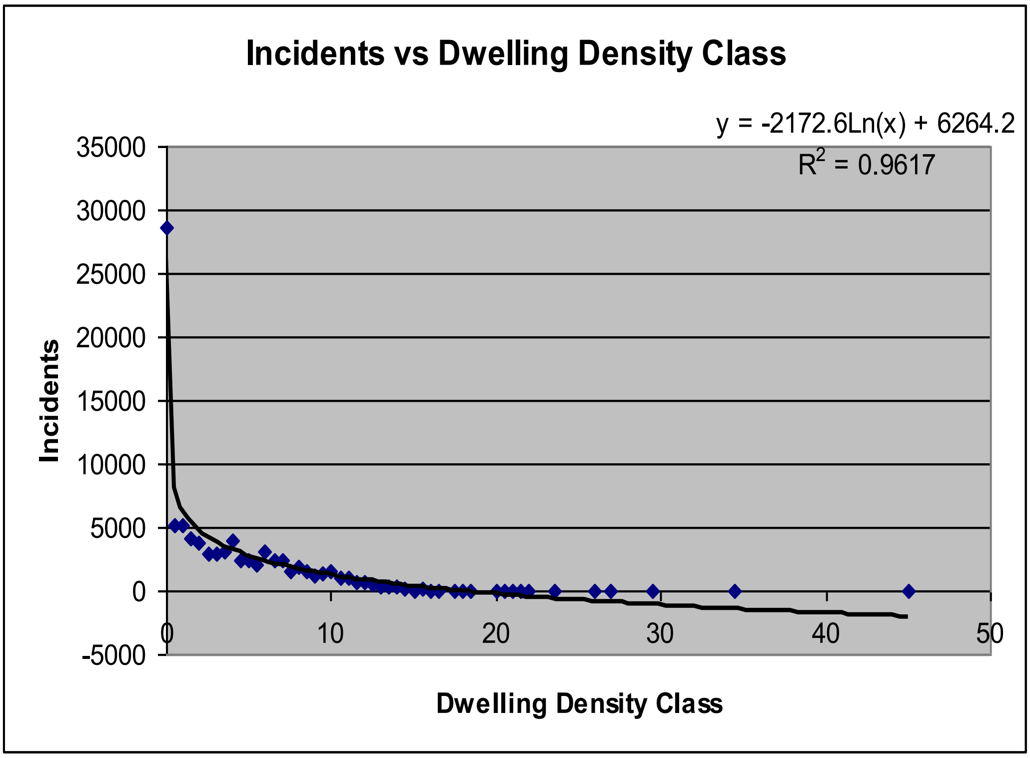

Figure 23. Total Incidents (1999-2001) vs 1996 Dwelling Density Class

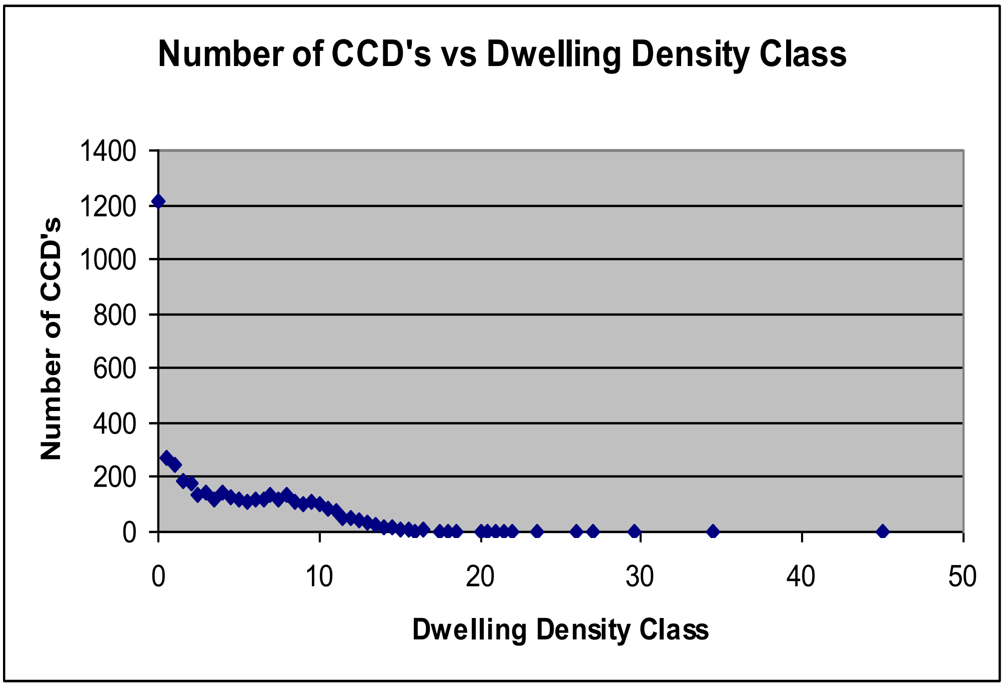

Figure 24. 1996 CCD's vs 1996 Dwelling Density Class

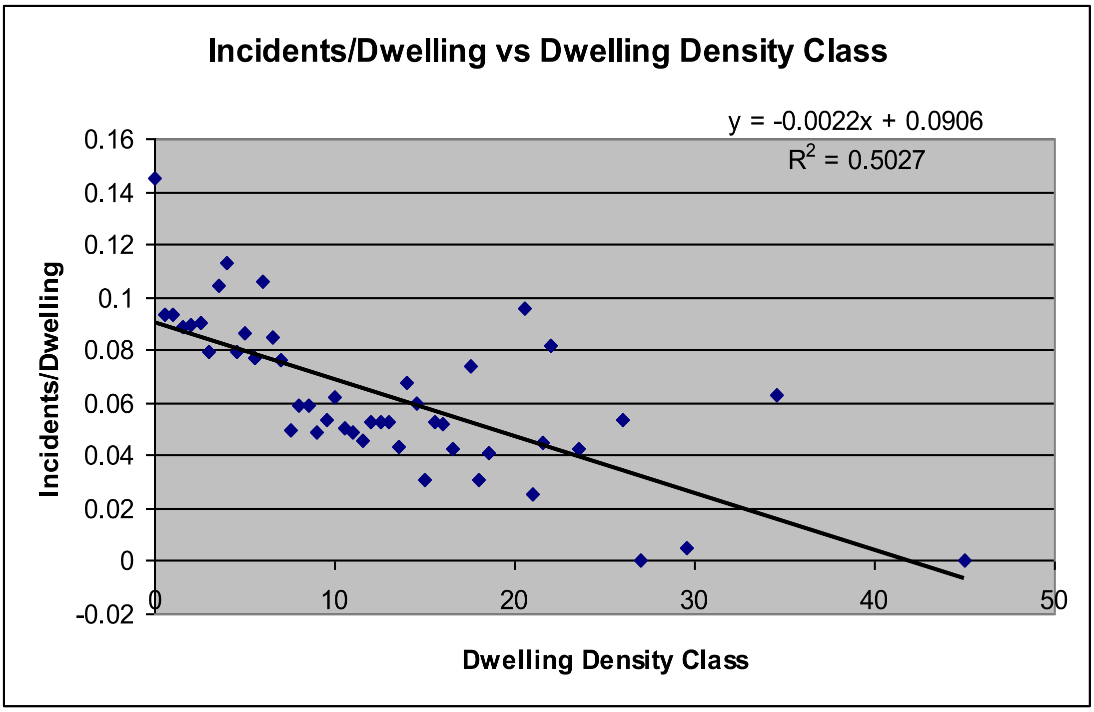

Figure 25. Incidents/Dwelling (1999-2001) vs 1996 Dwelling Density Class

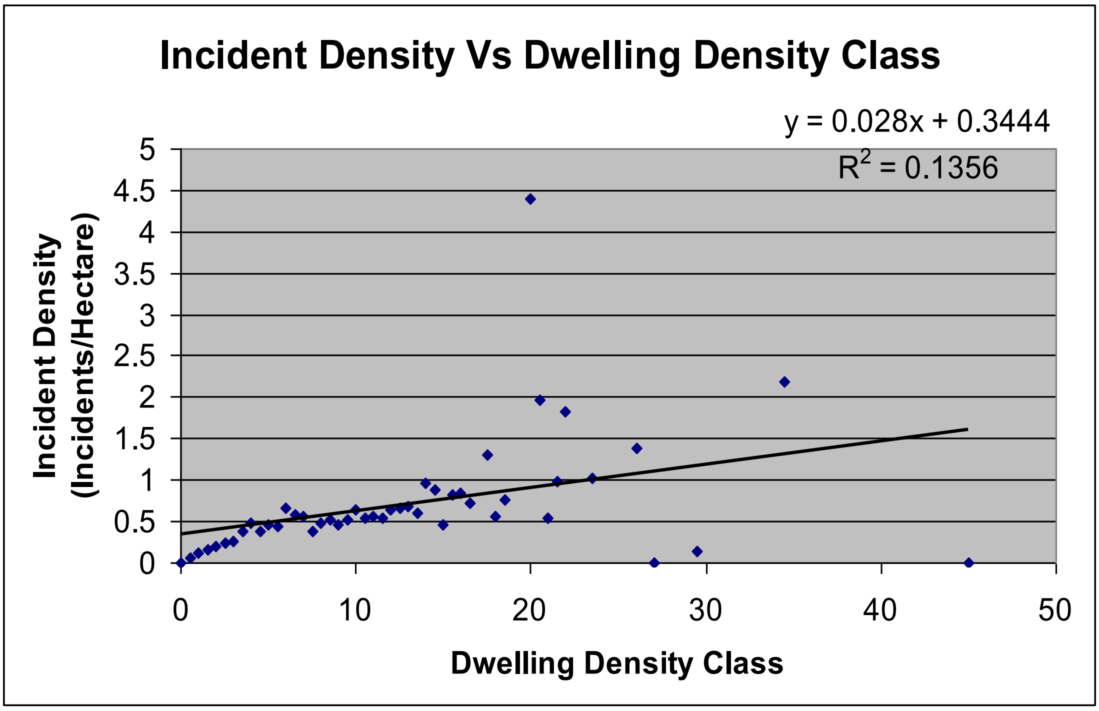

Figure 26. Incident Density (1999-2001) vs 1996 Dwelling Density Class

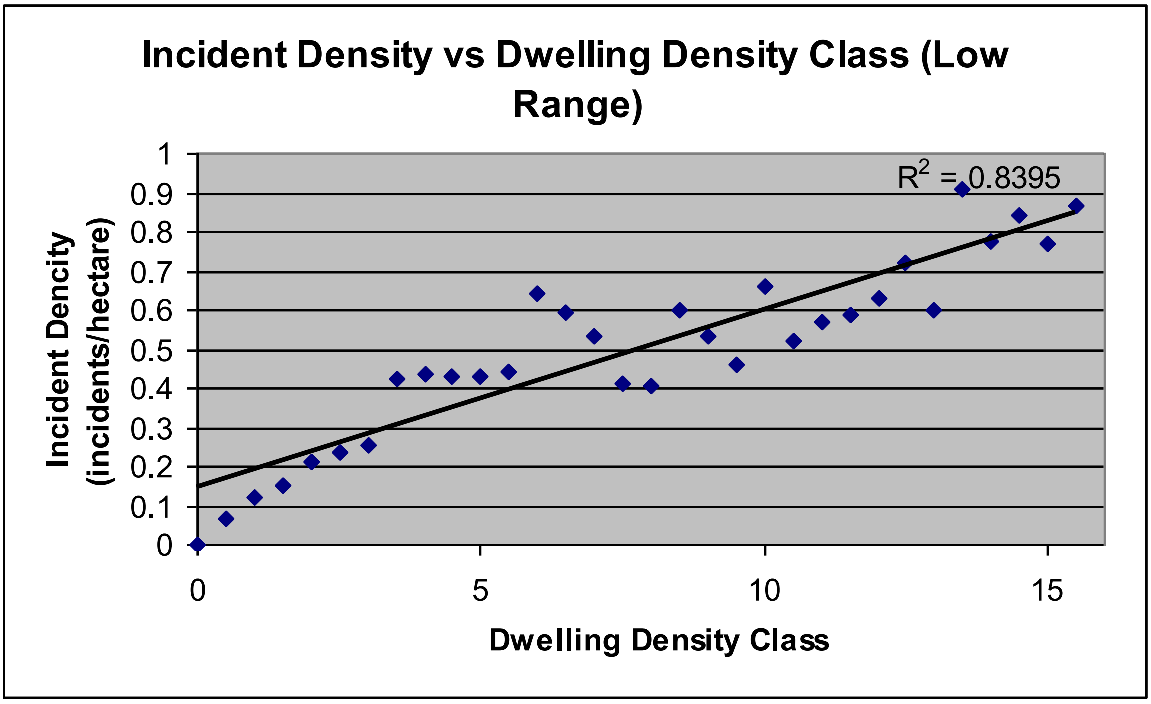

Figure 27. Incident Density (1999-2001) vs 1996 Dwelling Density Class (Low Range)

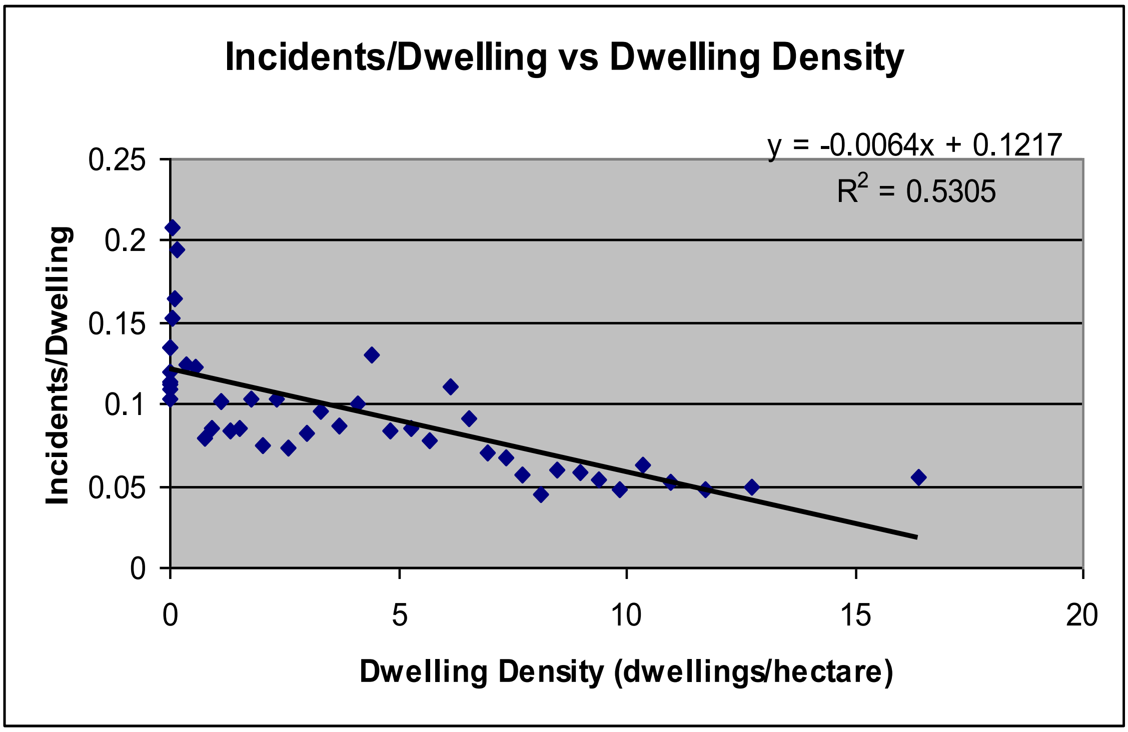

Figure 28. Incidents/Dwelling (1999-2001) vs 1996 Dwelling Density Groups

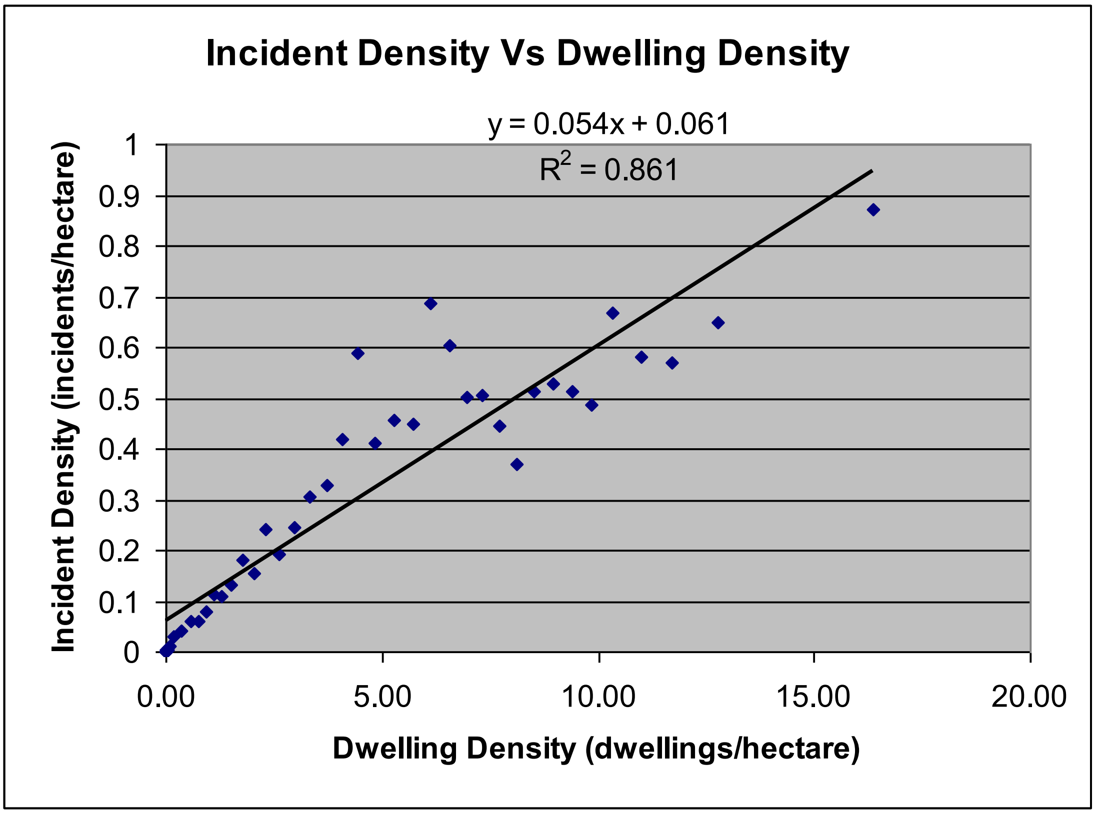

Figure 29. Incident Density (1999-2001) vs 1996 Dwelling Density Groups

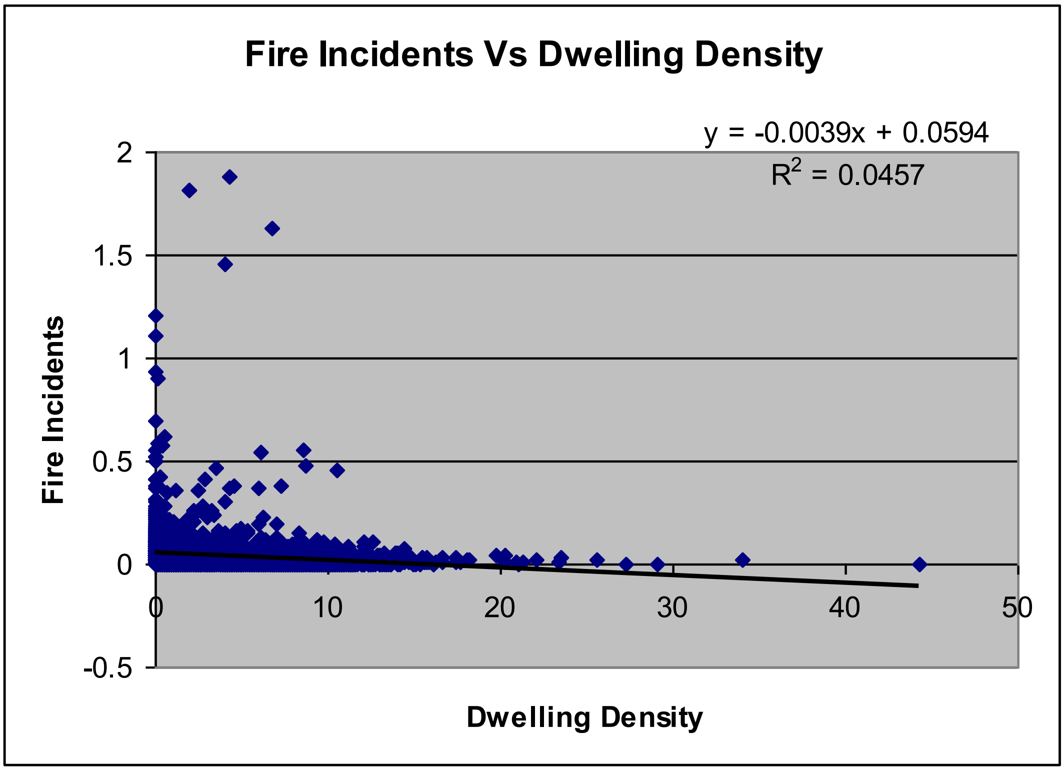

Figure 30. Fire Incidents (1999-2001) vs 1996 Dwelling Density

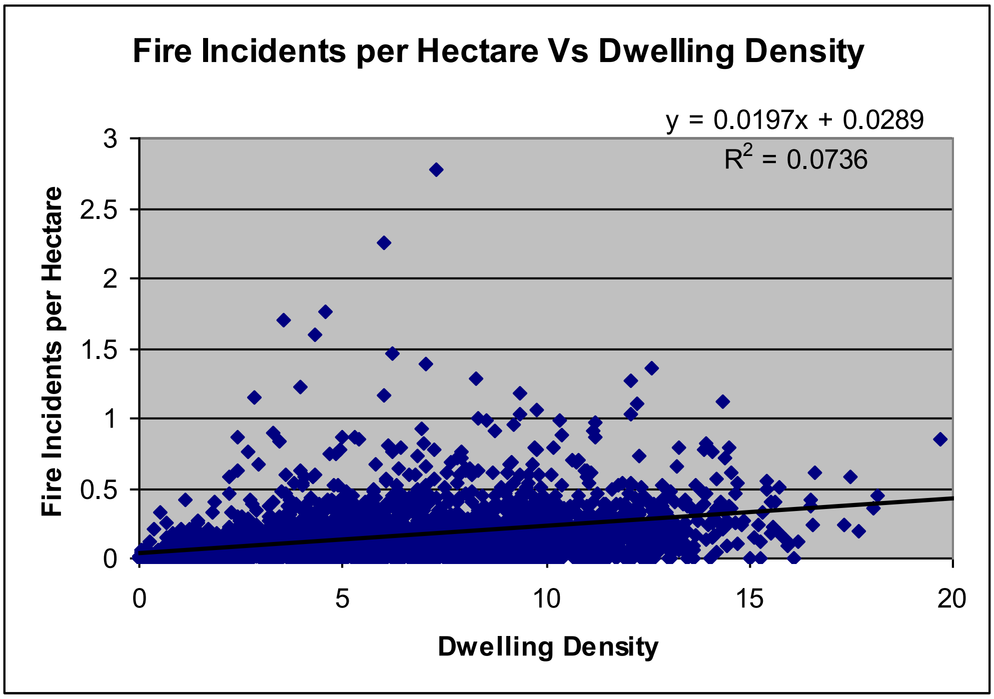

Figure 31. Fire Incident Density (1999-2001) vs 1996 Dwelling Density

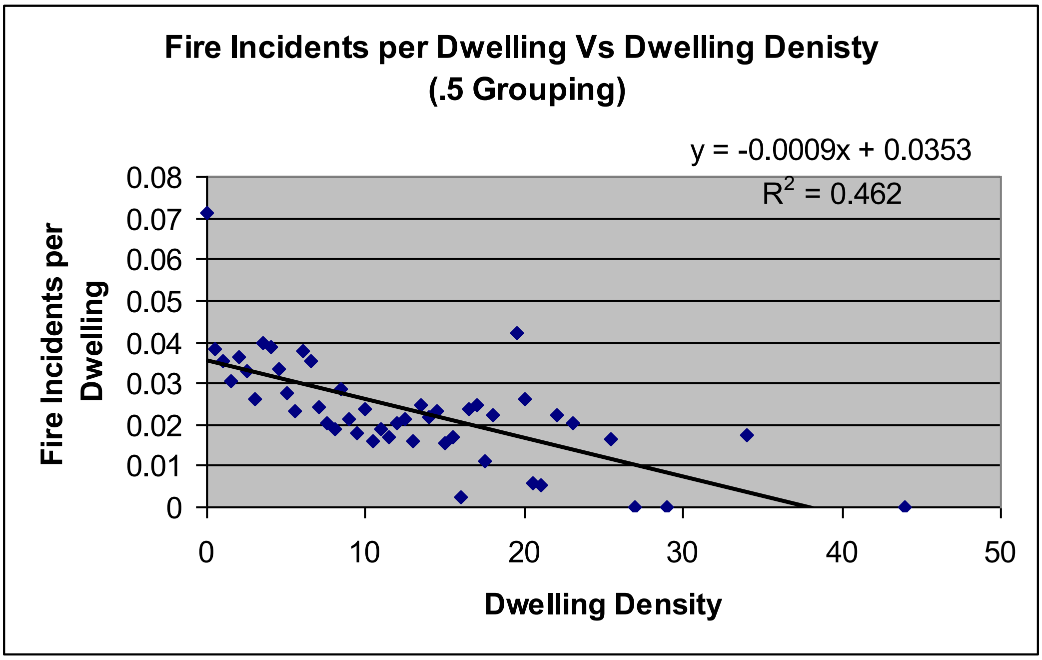

Figure 32. Fire Incidents/Dwelling (1999-2001) vs 1996Dwelling Density Class

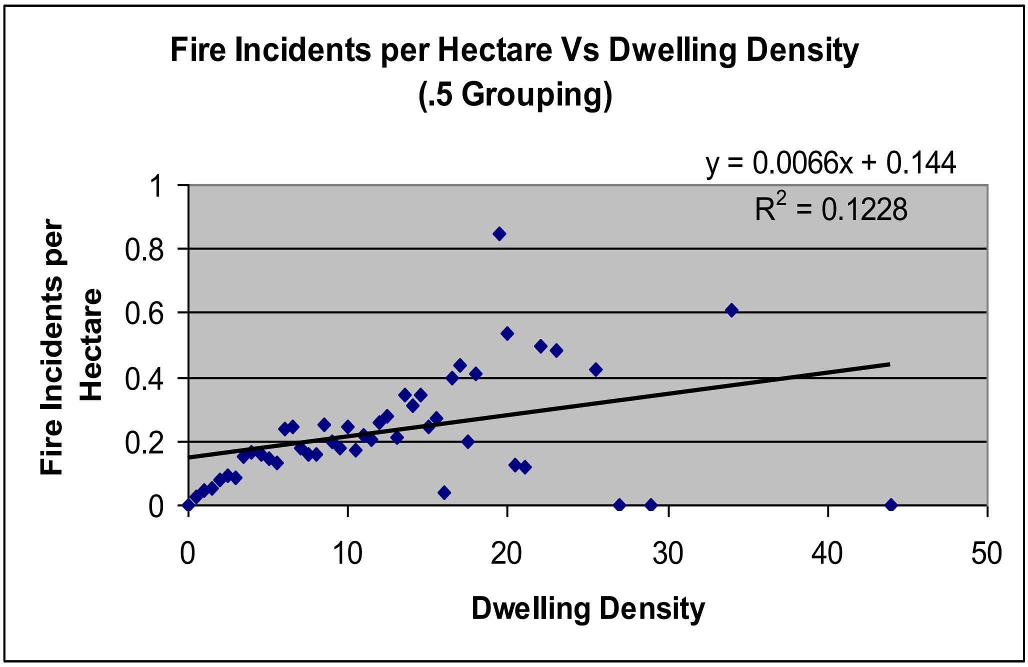

Figure 33. Fire Incident Density (1999-2001) vs 1996 Dwelling Density Class

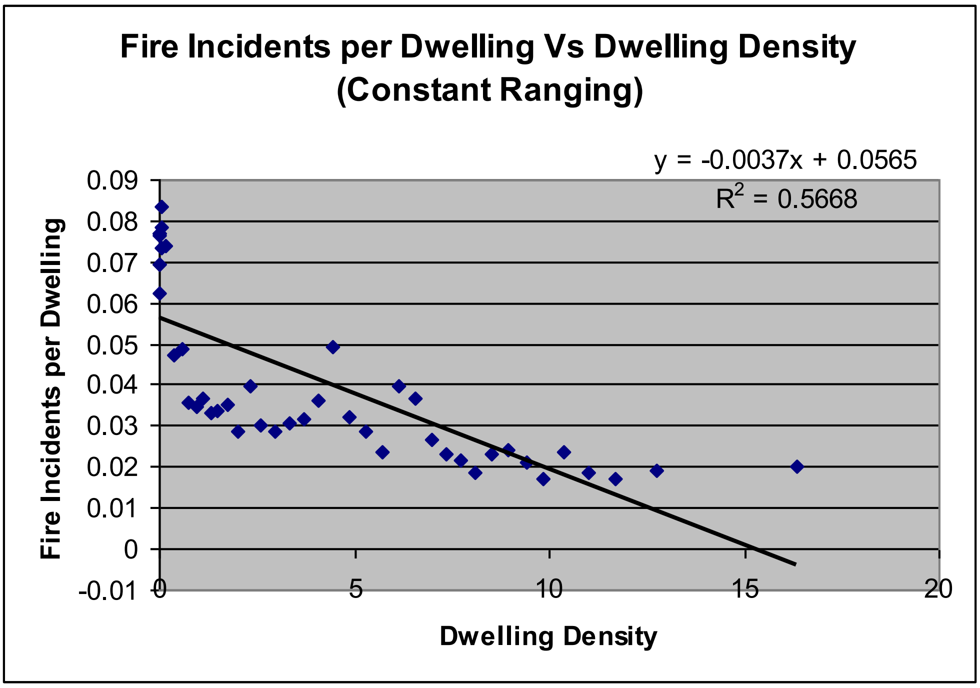

Figure 34. Fire Incidents/Dwelling (1999-2001) vs 1996 Dwelling Density Groups

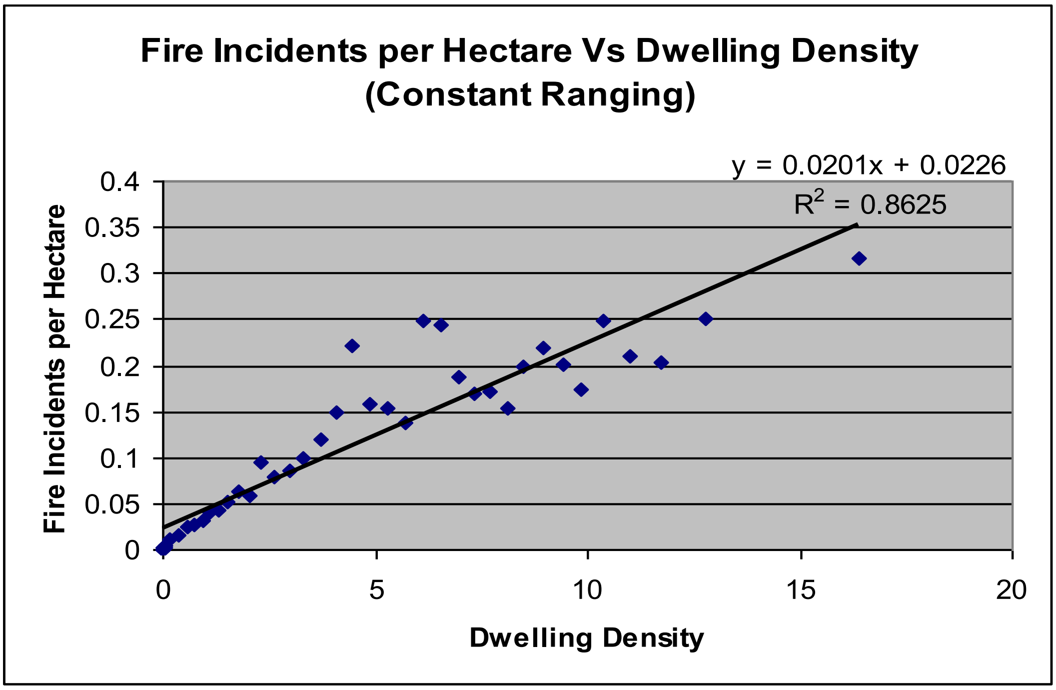

Figure 35. Fire Incident Density (1999-2001) vs 1996 Dwelling Density Groups

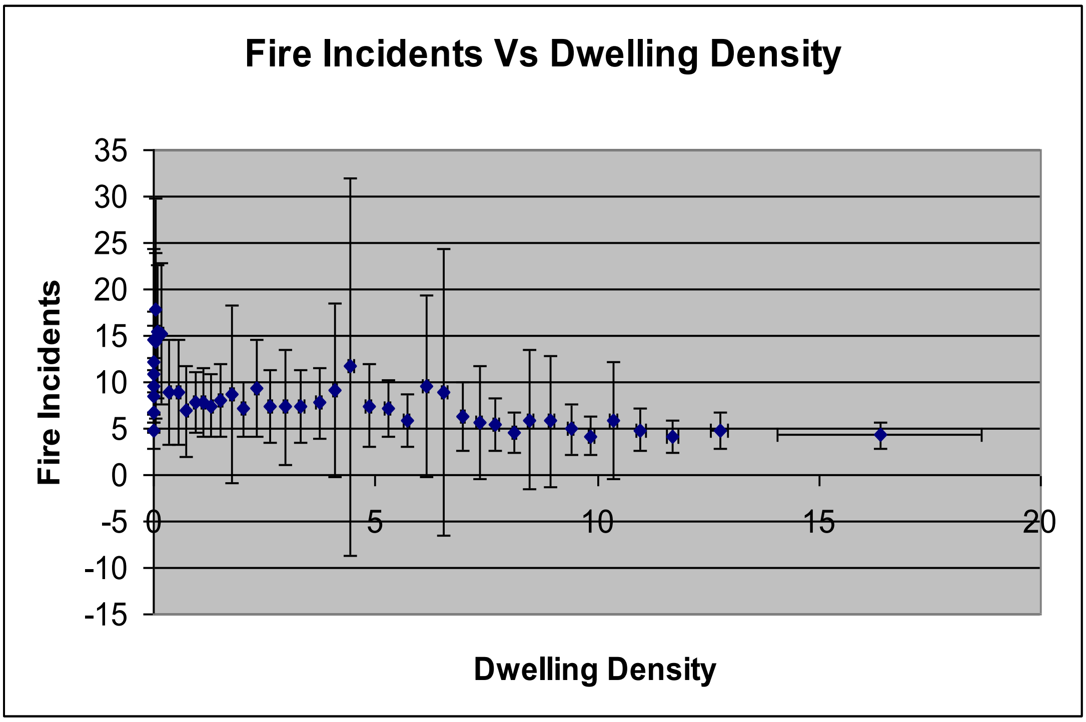

Figure 36. Fire Incidents/CCD (1999-2001) vs 1996 Dwelling Density Groups

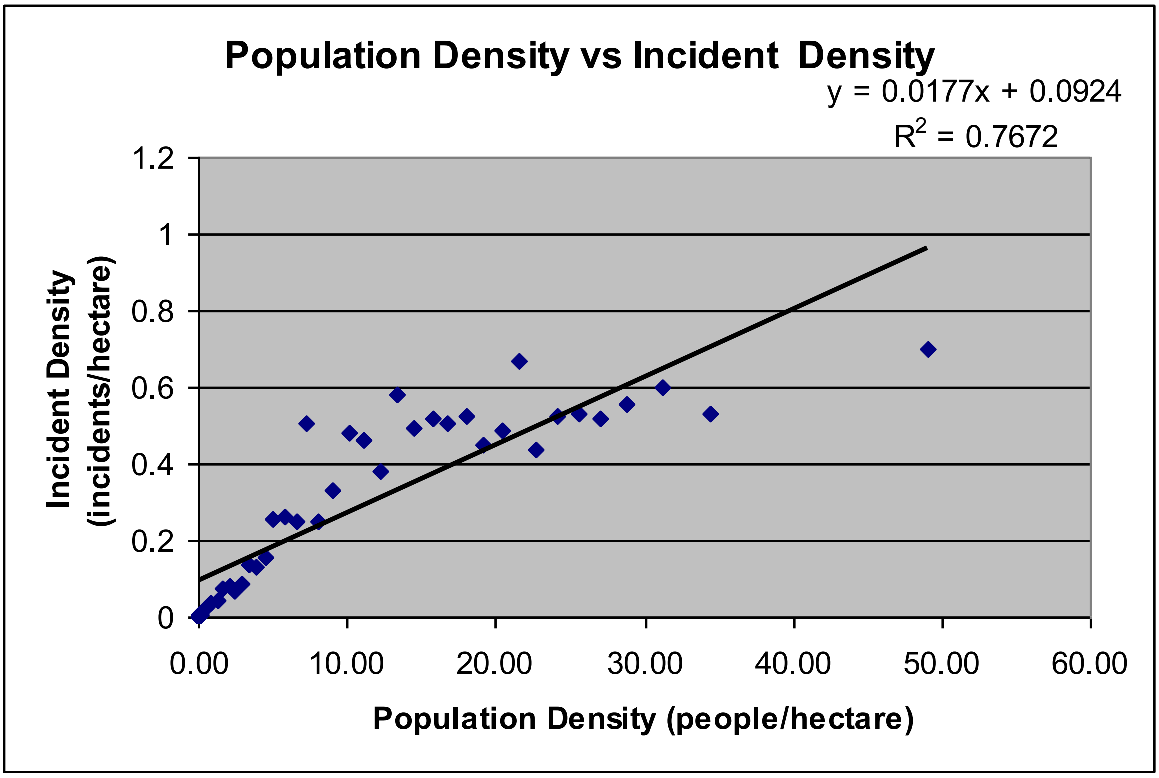

Figure 37. Incident Density (1999-2001) vs 1996 Population Density

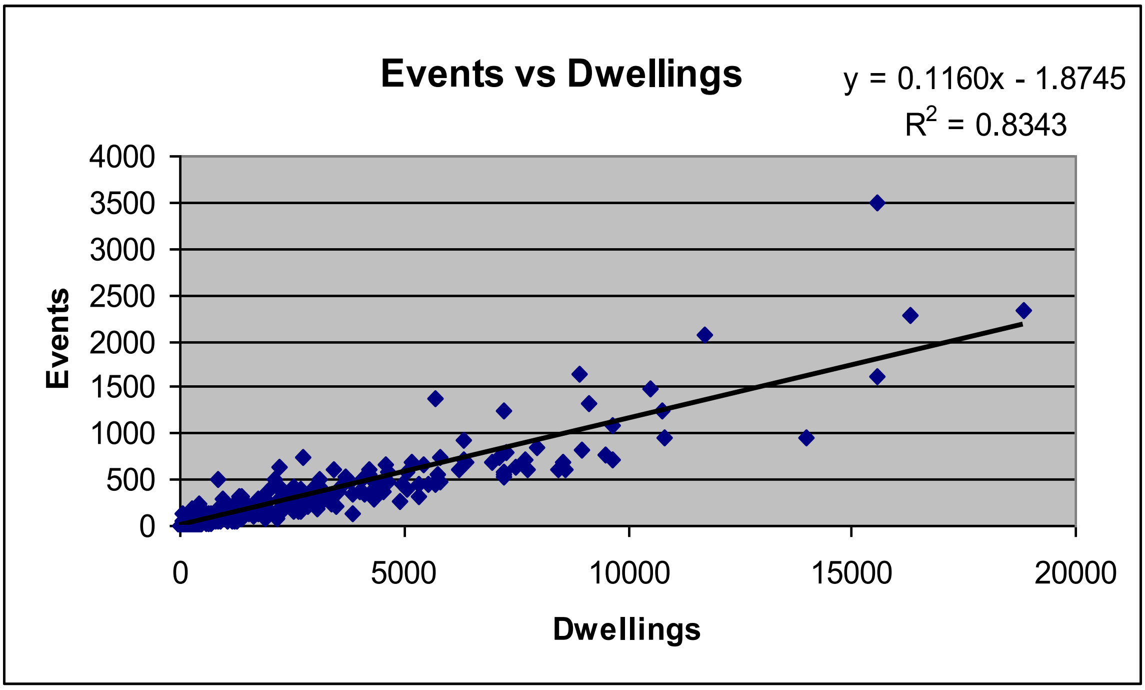

Figure 38. Total Incidents (1999-2001) vs 1996 POA Dwellings

Correlation Analysis of Dwelling Density and FIRS 99-01 Incidents

Databases Used:

Dwelling Density Analysis (derived from Master CCD Information)
Master CCD Information (derived from CFA Events All (1999-2001) and GIS 1996 Census data)

Related Files:

Make Dwelling Density Analysis (query)
Update to Create Ranges (query)
Group Dwelling Density Analysis (query)
Dwelling_Density_Analysis.xls

Purpose of Analysis:

This analysis is intended to correlate the dwelling density of a region and the number of incidents occurring in that region. Because new land release areas are defined by an area and a dwelling density for that area, this type of analysis is directly applicable to new developments.

Comments:

Most of the CCD's have extremely low dwelling densities. 33% have a dwelling density of less than one, 43% less than two, and 50% less then three.

Summary of Results:

The incident density (incidents/hectare) in an area seems to be strongly related to the dwelling density. Intuitively, this makes sense. As dwellings become closer together, more of the incidents will be tied to man-made structures, and the incident density will rise.

Incidents/person and incidents/dwelling tend to decreases as dwelling density rises. This may be because low dwelling density areas have a high proportion of wild fire incidents that are not associated with people or dwellings.

General Summary Data:

Jurisdiction: Country Fire Authority
Incidents analysed: 89281 incidents from FIRS 1999-2001 database
Base unit: CCD (4493 CCD's in CFA jurisdiction)
Area: 22,844,390.39 hectares
Population: 2,422,403 people
Max dwelling density: 44.3 dwellings/hectare
Min dwelling density: 0 dwellings/hectare

Analysis 1

Grouping Method:

Grouped in dwelling density ranges of three. For example, all CCD's with dwelling densities from 0 to 3 were grouped and the total incidents summed. The total incidents in each range were summed and plotted.

Incidents vs Dwelling Density Range

R^2 = not calculated
Comments:

This analysis simply reflects the number of incidents occurring within the dwelling density ranges. The plot shows a strong decreasing trend due to the greater number of CCD's with low dwelling densities. The 0-3 range contained 2,254 CCD's, with each successive range containing less.

Conclusions:

This simply shows that most incidents in the CFA jurisdiction occur in areas of low dwelling density. This is expected, because most of the CFA's jurisdiction has low dwelling densities. Approximately half of the CCD's in this jurisdiction have dwelling densities of three dwellings/hectare or less. These CCD's comprise 99.6% of the total land area in the CFA's jurisdiction.

Incidents/CCD vs Dwelling Density Range

$R^2 = 0.4914$
Comments:

The frequency of incidents per CCD appears to decrease slightly as dwelling density increases. However, this inverse relationship depends strongly on the data from the 27-30 and the 42-45 dwelling density ranges. The 27-30 dwelling density range contains only two CCD's, and should not significantly influence trend lines. Similarly, the 42-45 dwelling density range contains only one CCD. Ignoring these values, the inverse relationship is less strong.

Incidents/Hectare vs Dwelling Density Range

$R^2 = 0.0719$
Comments:

The incidents/hectare plot shows a direct relationship. Removing the 27-30 and the 42-45 dwelling density ranges results in a strong linear relationship ($R^2 = 0.8792$). This suggests that areas with a high dwelling density have a higher rate of incidents per hectare. Intuitively, the relationship makes sense. If there are more dwellings per hectare, there will probably be more emergency activity per hectare. This is confirmed by the slight upward trend realized considering all CCD's individually.

Because the majority of the CCD's in Victoria have low dwelling densities, most of the original data is grouped in the low dwelling density ranges. This may cause the plots to inaccurately represent actual trends. If all data points in the plots are weighted equally in the calculation of trend lines, the high dwelling density points representing relatively few CCD's have too much influence on the line.

Taking out all ranges with only one or two CCD's still results in a strong direct relationship between dwelling density and incident density ($R^2 = 0.7456$).

Also, this produces a fairly strong inverse relationship between dwelling density and CCD tracts ($R^2 = 0.5449$). This may be because CCD's with low dwelling densities are generally large in area (two keep approximately 200 households per CCD). These large CCD's will have may have more brushfires, etc.

Incidents/Person vs Dwelling Density Range

$R^2 = 0.3579$
Comments:

The incidents per person plot shows a slightly decreasing trend. Again, this is dependent on the two outlier data points. Removing these points preserves the negative trend, but reduces the R^2 value ($R^2 = 1370$).

Conclusions:

Intuitively, areas of low dwelling density will have many incidents per person because they will have many grassfires and wildfires not caused by humans.

Incidents/Dwelling vs Dwelling Density Range

$R^2 = 0.5601$
Comments:

The incidents per dwelling plot shows a decreasing trend. Again, this is dependent on the two outlier data points. Removing these points preserves the negative trend, but reduces the R^2 value ($R^2 = 4172$).

Conclusions:

Intuitively, areas of low dwelling density will have many incidents per dwelling because they will have many grassfires and wildfires not influenced by manmade dwellings.

Analysis 2

Grouping Method:

Grouped in dwelling density ranges of one-half. For example, all CCD's with dwelling densities from 0 to .5 were grouped and the total incidents summed. In the ensuing plots, trends were consistent up until the 15.5-16 dwellings density range. These "good" ranges all have information from at least eight CCD's. Considering dwelling densities up to 16 uses 99.4% of the CCD's in the CFA. This suggests creating groupings with a constant number of CCD's in each (with group sizes of at least eight).

Incidents/CCD vs Dwelling Density Range

$R^2 = 0.6916$
Comments:

The relationship is still decreasing, however the correlation is stronger.

Incidents/Hectare vs Dwelling Density Range

$R^2 = 0.8395$
Comments:
The relationship is still increasing with a strong correlation.

Incidents/Person vs Dwelling Density Range

$R^2 = 0.6160$
Comments:
The relationship is still decreasing, however the correlation is stronger.

Incidents/Dwelling vs Dwelling Density Range

$R^2 = 0.6637$
Comments:
The relationship is still decreasing, however the correlation is stronger.

Analysis 3

Grouping Method:
In order to remove the bias from the large number of CCD's with low dwelling densities, the CCD's were sorted by dwelling density and then grouped in sets of 100, creating 45 groups. Within each group, the dwelling density was averaged by CCD.

Incidents/CCD vs Dwelling Density Range

$R^2 = 0.2164$
Comments:
The relationship is still decreasing, however the is less strong, indicating that the number of incidents in a CCD is not significantly related to the dwelling density.

Incidents/Hectare vs Dwelling Density Range

$R^2 = 0.8606$
Comments:
The relationship is still increasing with a strong correlation. This is the strongest relationship between incidents and dwelling density.

Incidents/Person vs Dwelling Density Range

$R^2 = 0.5416$
Comments:
The relationship is still decreasing.

Incidents/Dwelling vs Dwelling Density Range

$R^2 = 0.5305$
Comments:

The relationship is still decreasing.

Correlation Analysis of Population and FIRS 99-01 Incidents

Databases Used:

Population_Analysis (derived from Master CCD Information)
Master CCD Information (derived from CFA Events All (1999-2001) and GIS 1996 Census data)

Related Files:

Population_Analysis.xls

Purpose of Analysis:

The population analysis was conducted to see if there were any relationships between Victoria's CCD populations and the CFA incidents, which occurred between 1999-2001. From an initial observation of the GIS data for Victoria's population and the FIRS incident database, it seems as though there is a strong relationship between these two variables. This analysis investigates this relationship by first looking at the CCD populations rather than the population densities.

Summary of Results:

The incident density (incidents/hectare) in an area seems to be strongly related to the dwelling density. Intuitively, this makes sense. As dwellings become closer together, more of the incidents will be tied to man-made structures, and the incident density will rise.

Incidents/person and incidents/dwelling tend to decreases as dwelling density rises. This may be because low dwelling density areas have a high proportion of wild fire incidents that are not associated with people or dwellings.

General Summary Data:

Jurisdiction: Country Fire Authority
Incidents analysed: 89281 incidents from FIRS 1999-2001 database
Base unit: CCD (4493 CCD's in CFA jurisdiction)
Area: 22,844,390.39 hectares
Population: 2,422,403 people
Min population: 0 people
Max population:

Analysis 1

Grouping Method:

The data was prepared for analysis by creating population ranges. The maximum CCD population was recorded (3195 people) and approximately 50 ranges were created with intervals of 60 (i.e. 0-59 and 60-119 people). The number of population ranges was arbitrarily chosen and seems to provide an even number of CCDs per range (although the breakdown of CCDs per range shows "normal" distribution with the maximum number of CCDs at the middle ranges).

Incidents vs CCD Population

$R^2 = 0.3356$
Comments:

In this analysis, the CFA incidents were compared to the CCD population ranges. This relationship seems to show "normal" distribution and appears to be heavily influenced by the relationship of CCD's to the CCD population ranges. This influence originates from the fact that some of the CCD Population Ranges contain many more CCD's than others. The numerous CCD's with in a certain population range cause the number of incidents within that population range to increase. So, from the appearance of the data, it seems that the incidents in a population range are a function of the number of CCD's within that same CCD.

Incidents/Hectare vs CCD Population

$R^2 = 0.0484$
Comments:

This study was conducted to try to normalize the number of incidents within in each CCD population range by dividing the number of CFA incidents within each CCD population range by the total area of the CCD population range. This relationship seems linear for lower CCD population ranges, but then becomes sporadic for the higher CCD population ranges. There also seems to be some "normal distribution" of the incidents per area compared to the CCD population ranges. This normal distribution could still be remnants from the influence of the number of CCD's with in each CCD population range.

Conclusions:

This study suggests, although the relationship is weak, that the number of incidents per area is directly related to the CCD population range. As the CCD population range increases, the number of incidents per area also increases.

Incidents/CCD vs CCD Population

$R^2 = 0.2269$
Comments:

This study was conducted as a continuation of the CFA Incidents/Area Vs CCD Population Range study. The ratio of incidents to CCD was taken to try and eliminate the influence of the number of CCDs within a CCD population range.

Dividing the number of incidents in each CCD population range, removed most of the affect of the number of CCDs contained in each CCD population range. This was intended to allow us to see how the number of CFA incidents related to area populations. Although the relationship between these two variables is relatively weak, the data suggests that the number of incidents per CD is directly related to the CCD population ranges.

Further investigation of population densities is required to accurately assess the relationship between the CFA incidents and the areas populations.

Correlation Analysis of Dwelling Density and FIRS 99-01 Fire Related Incidents

Databases Used:

Dwelling Density Analysis const - Fires only (derived from Master CCD

Information)

Dwelling Density Analysis const - Fires only (derived from Master CCD Information)

Master CCD Information (derived from CFA Events All (1999-2001) and GIS 1996 Census data)

Related Files:

Dwelling Density Analysis - Fires only-query (query)
Dwelling_Density_Analysis_Fires.xls

Purpose of Analysis:

This analysis is intended identify correlations between the number of fire related incidents that occurred in the past three years (1999-2001) and the dwelling density patters that exist across the state of Victoria. The identified correlations will allow the CFA to determine the expected changes in fire incident with the advent of new Department of Infrastructure land release areas.

Comments:

This analysis is similar to the *Correlation Analysis of Dwelling Density and FIRS 99-01 Incidents*, but this study only examines the relationship between dwelling density and the FIRS incidents that relate to fire. The fire incidents included in this study are: Non-structure, Open structure, road bound vehicle, structure/ building, vegetation, and undefined.

Most of the CCD's have extremely low dwelling densities. 33% have a dwelling density of less than one, 43% less than two, and 50% less then three.

Summary of Results:

The results of this study show that there is a relationship between the number of fires occurring in the CFA territory and Victoria's dwelling density. The analysis of fire incidents per hectare and fire incidents per dwelling expressed the strongest relationship to the dwelling density.

The same analyses were conducted using three different grouping methods. The first method used no grouping (averaging) of the dwelling and incident data contained with in each specific census collection district (CCD). The second method used a grouping style where all the information from CCDs with a dwelling density in a certain interval (0.5) were grouped together. This method produced 47 dwelling density ranges all with an interval of 0.5. The third method used a constant grouping technique where the dwelling density groups each consisted of 100 CCDs.

General Summary Data:

Jurisdiction: Country Fire Authority

Incidents analysed: 37218 incidents from FIRS 1999-2001 database

Type of Fire	Total Incidents
Non-Structure	6193
Open-Structure	2252
Road bound Vehicle	5716
Structure/Building	8053
Undefined	1896
Vegetation	13108

Base unit: CCD (4493 CCDs in CFA jurisdiction)
Area: 22,844,390.39 hectares
Population: 2,422,403 people
Max dwelling density: 44.3 dwellings/hectare
Min dwelling density: 0 dwellings/hectare

Analysis 1: Straight Comparison

In the straight comparison method, the information for each CCD was not grouped in any way. Each CCD represented by its own dwelling density, area, and count of fire related incidences. The information retained in each CCD was used to produce scatter plots relating the fire incident counts to the dwelling density of each CCD. Three plots were generated: Fire incidents Vs Dwelling Density, Fire incidents per Hectare Vs Dwelling Density, and Fire incidents per Dwelling Vs Dwelling Density.

Fire Incidents Vs Dwelling Density

$R^2 = 0.0242$

Comments:

This analysis expresses the un-averaged relationship between the number of incidents within a CCD and the number of incidents within a CCD.

Conclusions:

This simply shows that most incidents in the CFA jurisdiction occur in areas of low dwelling density. This is expected, because most of the CFA's jurisdiction has low dwelling densities. Approximately half of the CCD's in this jurisdiction have dwelling densities of three dwellings/hectare or less. These CCD's comprise 99.6% of the total land area in the CFA's jurisdiction.

Fire Incidents/Hectare vs Dwelling Density Range

$R^2 = 0.0736$

Comments:

This analysis shows the relationship between the number dwelling density of the CCD and the number of incidents per hectare within each CCD. The analysis suggests that areas with a high dwelling density have a slightly higher rate of incidents per hectare. Intuitively, the relationship makes sense. If there are more dwellings per hectare, there will most likely be more emergency activity per hectare. This is confirmed by the slight increasing trend realized considering all CCD's individually.

Because the majority of the CCD's in Victoria have low dwelling densities, most of the original data is grouped in the low dwelling density ranges. This means that there are many more data points representing the lower dwelling densities than there are data points representing the higher dwelling densities. This may cause the plots to inaccurately represent the actual trends because the higher dwelling densities are not adequately represented.

Conclusions: This plot does represent an increasing trend for the incident density (incidents/hectare) and dwelling density (dwellings/hectare) correlation but it does not provide convincing evidence that areas of high dwelling densities do in fact have more fire incidents than areas of lower dwelling densities. This correlation is not very convincing because of the low R^2 value achieved by this relationship.

Fire Incidents/Dwelling vs Dwelling Density

$R^2 = 0.0457$
Comments:

The incident per dwelling plot shows a decreasing trend. This means that as the dwelling densities increase, there are fewer incidents per dwelling. The makes sense because it suggests that, as dwelling density increases, the number of incidents in a unit area becomes less than the number of dwellings in a unit area. This may occur because high dwelling density areas have much more dwellings than they do fire incidents.

Conclusions:

Intuitively, areas of low dwelling density will have many incidents per dwelling because they will have many grassfires and wildfires not influenced by manmade dwellings. Although this plot shows a decreasing trend, it is not a very strong trend of which a model can be based because of the small R^2 value achieved from the correlation of the fire incidents per dwelling and the dwelling density.

Analysis 2: Dwelling Density Ranging (0.5 Intervals)

Grouping Method:

Grouped in dwelling density ranges of one-half. For example, all CCD's with dwelling densities from 0 to .5 were grouped and the total incidents summed. In the ensuing plots, trends were consistent up until the 15.5-16 dwellings density range. These lower ranges all have information from at least eight CCD's while ranges over 16 dwellings per hectare have less than 8 CCD's represented in each data point. Considering dwelling densities up to 16 uses 99.4% of the CCD's in the CFA. This suggests creating groupings with a constant number of CCD's in each (with group sizes of at least eight). This method will produce data that is averaged according to the dwelling density of each CCD, so the correlations discovered in this analysis will relate to averaged CCD data and will not be CCD specific. This averaging will

Fire Incidents Vs Dwelling Density Range

$R^2 = 0.1668$
Comments:

The relationship is still decreasing, however the correlation is stronger than with the ungrouped data.

Fire Incidents/Hectare Vs Dwelling Density Range

$R^2 = 0.1228$
Comments:

The relationship is still increasing with a strong correlation than the found in the ungrouped data analysis.

Fire Incidents/Dwelling vs Dwelling Density Range

$R^2 = 0.462$
Comments:

The relationship is still decreasing, however the correlation is stronger than with the ungrouped data.

Analysis 3: Constant Dwelling Density Ranging (Groups of 100)

Grouping Method:

In order to remove the bias from the large number of CCD's with low dwelling densities, the CCD's were sorted by dwelling density and then grouped in sets of 100, creating 45 groups. Within each group, the dwelling density was averaged across the CCDs with in the range. Constant grouping allowed for a uniform system of averaging for all of the data points, but will cause the correlation to be more general in nature and not spatially specific to any one CCD.

Fire Incidents vs Dwelling Density Range

$R^2 = 0.4228$
Comments:

The relationship is still decreasing, however the is less strong, indicating that the number of incidents in a CCD is not significantly related to the dwelling density.

Fire Incidents/Hectare vs Dwelling Density Range

$R^2 = 0.8625$
Comments:

The relationship is still increasing with a strong correlation. This is the strongest relationship between incidents and dwelling density.

Fire Incidents/Dwelling vs Dwelling Density Range

$R^2 = 0.5668$
Comments:

The relationship is still decreasing and the correlation between the two variables is stronger.

Appendix E: Ground Truthing

In order to verify the accuracy of the land release data obtained by the Department of Infrastructure, specific sites were selected and examined. This examination was initiated by overlaying a Victoria map directory with the Department of Infrastructure land release data using GIS software. Two distinct development areas were chosen for investigation: the Craigieburn area north of Melbourne and the Melton area west of Melbourne. The Craigieburn and Melton areas were chosen for investigation because they contain varying types of land development (See Figure 39 and Figure 40). Each number on the map in Figure 39 and Figure 40 represent a location where the development status was documented.

Locations 1 and 2 mainly consisted of grasslands and cow pastures with sparse tree coverage. According to the Department of Infrastructure, theses areas will be developed after 2010. We had expected that these areas would be grasslands that are flat and have very little vegetation due to the nature of Melbourne's northern suburbs. Figure 41 through Figure 44 show that this is indeed the case.

In location 3, there were mainly quarter hectare lots with houses that were already built. The housing was dense with approximately 1.5 to two meters between each house. This confirms that the land release data is accurate since this area was released in 1999 and there is currently thickly settled (See Figure 45 and Figure 46). Location 4, despite being adjacent to location 3, is still under development. This is obvious because the houses were still being built and there was a large amount of construction (See Figure 47 through Figure 50). The houses were mainly being constructed out of wood frames with brick exterior wall and slate or ceramic roofing. The residential development of this location confirms the land release data acquired from the DOI because that area was forecasted for development one to five years beyond 1999, according to the key in Figure 39. Similarly, locations 5 and 6 were also in different stages of development. The development ranged from fields that have not been developed yet to land being prepared for construction. There were houses still under construction, with some completed (See Figure 51 through Figure 54).

Next, we went to the Melton area in the western suburbs of Melbourne to do additional ground truthing (See Figure 40). We stopped at location 7 and found that it was similar to past locations. It was mainly grassland with no residential development. However, adjacent to that location was residential development that had just begun. This confirms the land release data shown in Figure 40 in that the area in location 7 is to be developed five to ten years after 1999. Location 10 was also similar to location 7 because it was mainly grassland with no residential development.

Of particular interest was location 8. This area had roads, sidewalks, lampposts, and fire hydrants. The houses however have not been built yet (See Figure 55 and Figure 56). There were also trees planted and lawns mown, making this location even more peculiar. This type of development was expected, however, because the area will be developed one to five years after 1999 according to the land release data in Figure 40.

When stopped at location 9, we saw there was dense housing. All of the housing was complete and some houses were even being repaired. This was expected because the land release data in Figure 40 showed that this area was released in 1996. Therefore it should be completely developed.

The ground truthing that we conducted was a good way to confirm that the land release data we obtained from the DOI was accurate. This allowed us integrate the data in our model with confidence.

Figure 39: Craigieburn Land Release Areas

Source: Department of Infrastructure and Melways Publishin

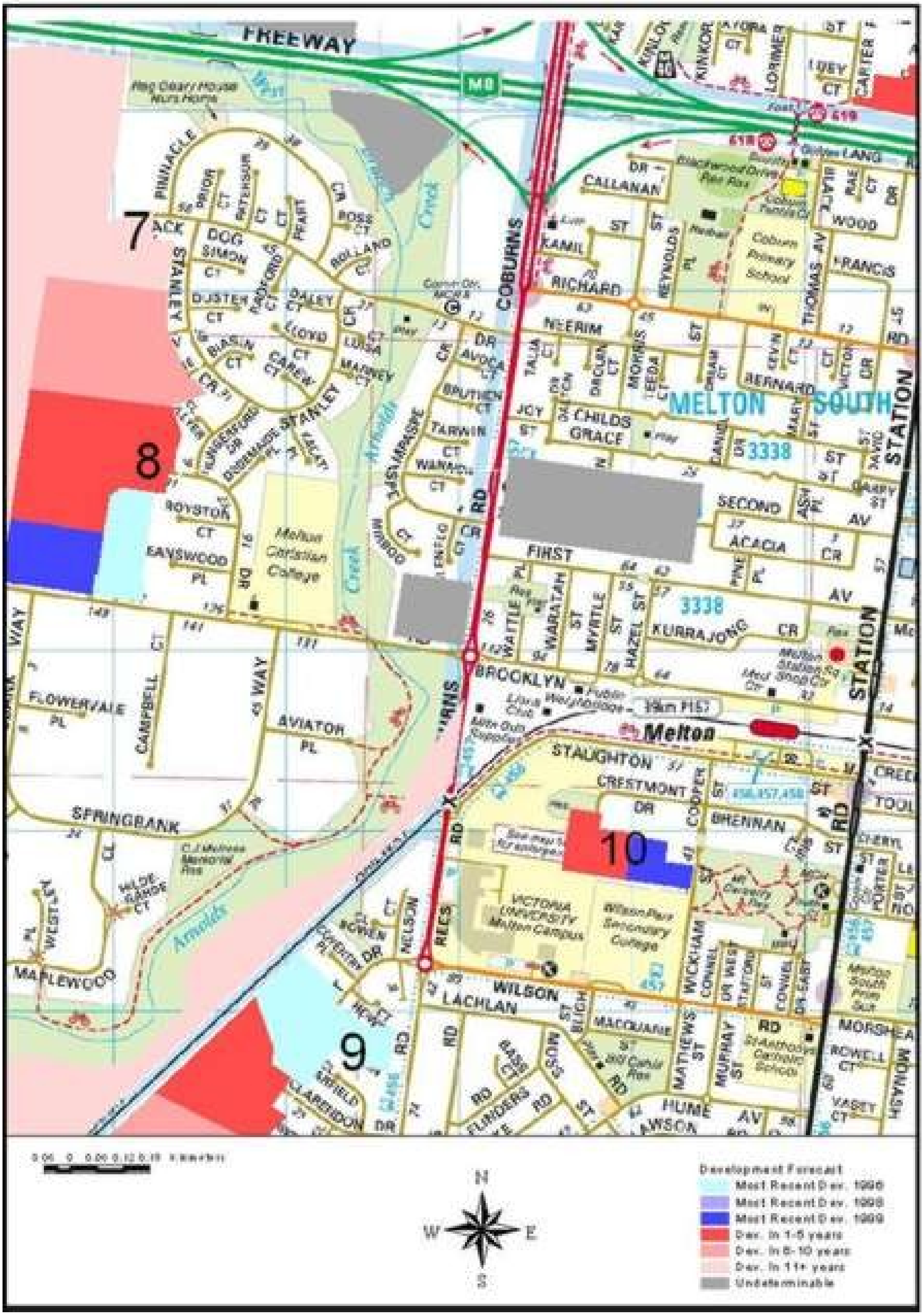

Figure 40: Melton Land Release Areas

Source: Department of Infrastructure and Melways Publishing

Figure 41: Location 1 Facing North

Figure 42: Location 1 Facing East

Figure 43: Location 1 Facing South

Figure 44: Location 2 Facing North

Figure 45: Location 3 Facing East

Figure 46: Location 3, Examples of Dense Housing

Figure 47: Location 4 Facing South East

Figure 48: Location 4 Facing West

Figure 49: Location 4 Construction

Figure 50: Location 4 Facing South at More Housing Developments

Figure 51: Location 5 Facing South

Figure 52: Location 5 Facing East

Figure 53: Location 5 Facing North East

Figure 54: Location 6 Facing North

Figure 55: Location 8 Facing North

Figure 56: Location 8 Facing West

Appendix F: Social Implications of the Project

This project developed a modelling method for the forecasting of emergency incidents within the CFA's jurisdiction, produced short, medium, and long-term forecasts, and translated the forecasts into a preliminary fire threat analysis. The projected increase in emergency incidents that the CFA will be responding to is based on the residential development projections for the outer suburbs of Melbourne. Thus, this project provides a concrete link between urban sprawl and emergency fire services. Immediate social implications pertaining to the CFA include responding to the increased demand for fire services, and achieving and maintaining equitable fire coverage across Victoria. Relevant social issues beyond the CFA include the consequences of urban sprawl and urban growth policy.

The forecasted increase in emergency incidents implies an increasing demand for the fire protection services provided by the CFA. The CFA's response to this increasing demand will effect the safety of Victoria's communities. If the CFA does not adapt to the changing fire threats, developing communities will be at risk. The CFA's manpower, trucks, equipment, and funding will have to be increased or redistributed to meet the incident increases forecasted in this project to safeguard communities from fire disaster.

As the fire threat across Victoria changes, the CFA continuously works to ensure that fire protection is equitable for all areas within the CFA's jurisdiction. Forecasting where emergency incidents are going to increase has the potential to assist the CFA develop plans to maintain equitability. Areas with a high frequency of fires will require substantial resources to provide a level of safety equal to areas that experience few fires. If the CFA can grow and adapt concurrent with the changing fire conditions, it can maintain equal fire protection.

The increase in emergency incidents forecasted by this project is a direct result of the projected urban sprawl in the Melbourne area. The city has already extended to the east as far as possible before running into the Dandenong Ranges, and is now growing into grasslands in other directions. Melton to the west, Craigieburn to the north, and Casey to the southeast are all experiencing significant development that is expected to continue into the next decade and beyond. This growth will place an increased burden on the CFA, as well as other emergency response and public services. This will require increased funds. However, the source of these funds is debatable. Should the general public be responsible for funding increased services that will benefit only those moving into new residential areas? To what extent are the developers be responsible for funding services in communities they construct? These issues are brought to bear by the increasing CFA work load demonstrated by this project.

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