

Fire Research Report

Measurement of Rural Fire Fighter Physiological Workload & Fire Suppression Productivity

Centre for Human Factors
and Ergonomics

May 2008

This research determined, under New Zealand operational conditions, the physiological workload of some rural firefighting tasks. At the same time, the research measured fire suppression productivity under real operational conditions. The project necessitated the development of a novel suite of data collection equipment worn by the firefighter to record visual, physiological and geographical information relevant to firefighting.

Results from the research indicate that rural fire suppression (and ignition) tasks are indeed physically demanding. Average heart rates in excess of 120 beats per minute were recorded in most tasks (water and hand tool mop up). Periods of extremely heavy workload with heart rates above 150 beats per minute were experienced in all tasks.

An unanticipated benefit of intensive data collection from wearable devices at fires was that it provides excellent training material. In addition, a method was developed using Google Earth, to present the path of the firefighter in a 3D terrain model. This allows for a much greater understanding of physical environment in which fire are fought in New Zealand.

Now that the data collection ensemble is mature the emphasis will be on enlarging the data set with data collection at training and more real fires.

New Zealand Fire Service Commission Research Report Number 92
ISBN Number 978-1-877349-88-1 (on-line)
ISBN Number 978-1-877349-89-8 (paperback)
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Research Report

New Zealand Fire Service Commission Contestable Research Fund

Measurement of Rural Fire Fighter Physiological Workload and Fire Suppression Productivity

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1. Introduction

This research project aimed to improve the health and safety of rural firefighters by determining, under New Zealand operational conditions, the physiological workload of firefighting tasks. At the same time, the research measured fire suppression productivity under real fire conditions. The project necessitated the development of a novel suite of data collection equipment worn by the firefighter to record visual, physiological and geographical information relevant to firefighting. Results from the research quantify firefighter physical workload and fire suppression productivity under real fire conditions.

Project Aims

This research project utilises a newly-developed research methodology to measure workload and productivity of New Zealand firefighters under real fire fighting conditions. Rural firefighting is a hazardous and physically demanding task requiring a high level of fitness for productive front line operations. Firefighters often endure high levels of heat, are exposed to excessive smoke and dust, carry heavy equipment over often difficult terrain, and are expected to work at a high physiological load for extended periods. The aim of the proposed research programme is to improve the health and safety of rural firefighters by determining, under New Zealand operational conditions, the physiological workload associated with rural firefighting tasks and to relate this to their actual fire suppression productivity.

This research will complement related national and international research but, importantly, provide information on workload associated with uniquely New Zealand conditions. This specifically relates to the firefighting equipment, suppression techniques, fuel types and environmental conditions found in New Zealand.

Project Objectives

1. Measure the actual physiological workload and productivity associated with rural firefighting tasks under New Zealand conditions at real fires.
2. Relate measured workload and productivity for firefighting tasks to fitness and productivity requirements.
3. Provide input to guidelines for fatigue recommendations and productivity standards.

2. Literature review

Executive Summary of the review

The principles of physiological testing have been well established for a number of decades. The methods have been predominantly developed for controlled laboratory conditions with simulated tasks, but some more robust field equipment ensembles have also evolved, with affordable versions of heart rate monitors for example now widely available.

Similarly, proven task analysis methods have been used within relevant sectors for many years; but again, generally with a researcher present to observe, record and ensure proper functioning of any equipment.

A limitation of field data collection systems for rural fighting studies however, is that due to the number of continuous hours of the operations, they require longlife power sources and data capture/logging capability. Monitoring systems also cannot be supported in the field by scientists or technicians unless these people are adequately trained so as not to impede the crew or compromise safety. The equipment also needs to function adequately in the presence of extreme heat, moisture and dust.

These factors in combination have resulted in a paucity of both physiological performance and task analysis data from operationally-based studies. We do not have enough objectively-derived understanding about physiological characteristics under real firefighting conditions, and we have no evidence base at all regarding how physiological performance is linked to specific tasks, or real-time specific operational scenarios. The ability to predict patterns of fatigue and performance decrement are therefore very limited. Case studies – widely regarded as an invaluable training resource, are therefore limited to subjective accounts of the human responses involved. The forensic psychology literature on the unreliability of eye-witness accounts following high-stress episodes is extensive and conclusive. No matter how honestly the subjects try to recount accurately, subjective data is therefore not going to be reliable or comprehensive enough. Objective data is essential.

The inability of firefighters in action to communicate interactively with remote supervisors with a better overview of the operation has also been linked to poor decision-making resulting in fatalities and some developments have been pursued to address this.

The literature provides broad support for the methods proposed for the field component of this research. It also indicates potential for an extension of the techniques suggested, at this or a later stage. The inclusion of recorded crew audio transmissions as an additional channel would lock in real time supervisory interactions and extend the analysis further beyond the individual into the wider work system.

This literature review aimed to identify relevant overseas and New Zealand studies on the measurement of physiological workload and performance amongst rural firefighters and other allied occupations - such as military and forestry sectors

The literature review material was drawn from searches of the following sources:

- Ergonomics Abstracts
- Web of Science
- Google Scholar
- Author-specific: for example, Heil, D., Gaskill, S., Sharkey, B., Ruby, B.
- Journal-specific searches: *International Journal of Wildland Fire*,, *Applied Ergonomics*, *Engineering in Medicine and Biology Magazine*, *Ergonomics*
- Organisations
 - USDA Forest Service Technology and Development Centers, Missoula, Montana & San Dimas, California
 - US Army
 - US Army RD&E Center, Natick. Future Force Warrior program. <http://ffw.natick.army.mil/index.htm>
 - Warfighter Physiological Status Monitoring (WPSM), from <http://www.usariem.army.mil/wpsm/index.html>
 - Performance Measurement (<http://www.army.mil/escc/pfm/index.htm>)
 - Physiological Monitoring and Predictive Modeling, from http://www.momrp.org/physio_index.html
 - Noldus (Netherlands)

Keywords and phrases used in the database search were: physiological workload, physiology, measurement, physiol* measures, real-time, event recording, wildland, firefighting, firefighter, rural fire, military, forestry, logging, operational, emergency services, warfighter, task analysis, synchroniz(s)ed monitoring, telemonitoring

Inclusion criteria:

- Studies describing methods that could be applied under real operating conditions; generic studies on physiological measurement were excluded unless they were highly significant pieces of work.
- Occupationally based studies. Sports science studies focussed on elite performance that were not applicable to the wider working population were excluded.
- Studies published before 1990 excluded unless highly significant

- Data from formally peer reviewed material was assumed to be more reliable than other sources and discussions weighted accordingly where inconsistencies in the literature arose. Journal papers, book chapters, conference papers, and reports from major research centres were, in turn, assumed to be more authoritative than trade magazine articles, newspaper items, student assignments or personal communications on the same topics.

The following factors limited the conclusiveness of the review:

- Differences in definitions, classifications and terminology between countries
- Inconsistency and gaps in the literature
- The unavailability of some relevant industry research data due to commercial sensitivity
- Lack of critical peer-reviewed papers assessing new monitoring/measuring equipment. Publication lag for academic papers of two years is common, by which time manufacturers have produced new versions of the product in question. This is particularly problematic in fast moving markets such as software design.

2.1 Physiological monitoring

Forestry and fire occupations

Many tasks in rural fire fighting are physically demanding (Budd, 2001; Gaskill, 2002; Heil, 2002) and result in high levels of fatigue. To date, much research work has been carried out by Australian and North American researchers to quantify total energy expenditure and associated fatigue (Ruby, Scholler, & Sharkey, 2000, 2001; Ruby, Zderic, Burks, Tysk, & Sharkey, 1999). However, there are no published reports of studies with measured data of New Zealand rural firefighter workload and fatigue. Fire behaviour, work practices, climate and equipment in New Zealand differ from those in Australia, the United States and Canada.

There is however, much physiological research that has been carried out in the New Zealand logging industry (e.g. Parker, Bentley, & Ashby, 2002; Parker & Kirk, 1994) that is of relevance. Logging is recognised as one of the most physically demanding of full time occupations (Gaskin, 1990; Kukkonen-Harjula, 1984; Parker, Sullman, Kirk, & Ford, 1999) and exhibits many parallels with fire fighting tasks. Both loggers and firefighters are exposed to environmental weather extremes, high physiological workloads and work for extended periods, often handling heavy tools in potentially dangerous conditions. Measurement of overall energy usage is remarkably similar between rural firefighters (Heil, 2002; Ruby *et al.*, 2002) and loggers (Kukkonen-Harjula, 1984) with both expending approximately 4700 kcal/day.

The measurement of physiological workload is necessary for the understanding of factors which contribute to fatigue and for providing a measure of the subsequent success of fatigue management programmes. Physiological workload also provides a quantitative measure of the physical requirements of a task. Then, if that task is modified the effects can be measured in a repeatable and unambiguous way.

There are complex interactions among three factors; work practices, work behaviour and clothing which together influence the firefighter's heat load and level of fatigue (Brotherhood *et al.*, 1997c; Budd, 2001; Budd *et al.*, 1997c; Gaskill, 2002). New work techniques, items of equipment and work organisation can be tested to determine if they alter the physiological workload of the firefighter. If a new technique, item of equipment or way of organising work does impose a greater physiological load it will likely not be used and further modifications and developments would be necessary for successful introduction (Budd *et al.*, 1997i). These tests would not be conducted in operational settings however.

Physiological testing in urban fire has been extensive, but only in simulated conditions. Recent non-operational studies include those by Von Heimburg, Rasmussen, & Medbo (2006), Bruce-Low, Cotterrell, & Jones (2007) and McLellan & Selkirk (2006). It is interesting to note that the testing in simulated conditions is taken as the norm to the extent that in the latter paper it is not explicitly stated in the abstract.

An ever-present limitation is the logistical difficulty, and cost, of conducting rigorous experimentation over long and indeterminate periods without scientific backup (Heil, 2002). The use of the doubly labelled water (DLW) test, described by Ruby *et al.* (2002) as the gold standard for the measurement of total energy expenditure in free-living individuals, for example is far more problematic in an operational environment where sampling by specialists cannot be as strictly controlled. For example, the use of electronic activity monitors that can be worn on the clothing is complicated by the need to establish validity of the algorithms through further controlled trials (Heil, 2004) – which by definition are highly controlled simulations.

Other industries

Telemonitoring is a growing area in medical (Meystre, 2005) and particularly military (Jovanov, O'Donnell-Lords, Raskovic, Cox, Adhami & Andrasik, 2003) applications. It is defined by Meystre (2005) as the use of information technology including audio and video to monitor patient physiology at a distance. Dating from the earliest recorded transmission of electrocardiograms (ECGs) using telephone lines back in 1905, telemonitoring is now well established use in the emergency services and care of the elderly, the scope of real-time monitoring are predicted by Meystre (2005) to increase through the use of virtual reality, immersive environments, haptic feedback and nanotechnology.

While well proven, medical systems are mostly designed for use in controlled situations with trained personnel such as ambulance staff in attendance.

For occupational applications in harsh environmental settings, the most established system appears to be the Warfighter Physiological Status Monitoring (WPSM) program (Jovanov *et al.*, 2003). It is described as:
a multi-institute research program focused on gathering, archiving, and interpreting physiologic data from warfighters in the field. The ultimate goal is to develop a suite of wearable sensors to provide critical physiologic information to commanders and medics. Biosensors, personal area networking, and data management hardware and software provide a wealth of physiologic information within a broader environmental framework. Data are used to develop models of thermal stress, hydration status, cognitive state, etc.

The system aims to provide feedback to commanders on healthy soldiers that will allow them to monitor fatigue, dehydration and therefore combat readiness. For injured troops the system provides data on the location and medical status of the soldiers, allowing more effective triage and recovery (Wexford, 2003).

Critical reviews of the WPSM are not yet available in the peer-reviewed literature.

2.2. Real-time Task Analysis and performance monitoring

Forestry and fire occupations

Task analysis is defined as “the study of what an operator (or team of operators) is required to do, in terms of actions and/or cognitive processes, to achieve a system goal” (Kirwan & Ainsworth, 1992). While generic training documentation abounds, the specific tasks required of a rural firefighter during forest fires cannot be totally predetermined. As observed by General Patton, no battle plan survives contact with the enemy.

There is an absence of real-time monitoring systems that can record instructions given to individuals and teams, as well as their responses. Presumably this makes it currently impractical to document what they should ideally have been doing minute by minute; and impossible to track what they actually did.

Productivity of initial attack crews and more specifically of fireline construction has been of interest for many years and has been the subject of numerous studies. Surprisingly few studies though have measured productivity under real fire conditions, in almost all cases the tasks have been simulated. Little new data has been published, since the commonly cited studies of Schmidt

and Rinehart (1982), and Barney *et al.* (1992), and most of the studies have produced either limited or extremely variable data, calling into question the validity and applicability of the resulting guidelines. Most of the current guidelines are adapted from these early studies, although their validity is enhanced through application of local conditions and of expert knowledge and information.

Therefore, the need for information specific to New Zealand conditions remains, and this combined with the availability of new technology, in particular for monitoring the effects and importance of human factors, means that significant advances and improvements can (and should) be made to existing data and guidelines through research on productivity of fire suppression resource types mobilised in New Zealand.

Studies measuring total energy expenditure over the course of a day (Heil, 2004) are attractive in their simplicity but neglect to describe peaks of activity that may be the cause of physical system failure or poor decision-making, leading for example, to entrapment of crew. It is of course important to take into account the fact that people carrying out such tasks will burn twice the energy of more sedentary workers. However, heavily equipped personnel can reach a level of fatigue at which they are incapable of executing the immediate task asked of them – with ensuing risk of death - a lot quicker than in the time taken to expend 4000 kcal. Minute by minute tracking of actual workload and task demands is essential.

Other industries

Researched aerospace situations are predominantly sedentary in controlled environments and with little direct relevance to active rural firefighting.

In manufacturing, direct observation with remote analysis using video and commonly available software is reported in recent case studies by Gilad & Elnekave (2006). They describe it as ‘a time-based approach to obtain quantitative measures for ergonomics hazard analysis. The software provides semi-automatic sampling of work cycles, and snapshot observations are made on frozen video frames that can be analysed expertly at a distance from the workplace to highlight biomechanical concerns. The system views the actor, rather than also displaying what the actor is seeing and doing in detail.

More advanced systems available to ergonomists working in occupational settings are those based on products used in animal behaviour studies. Most heavily reported of these is the Noldus Observer system based in Holland. The Observer Video-Pro system was first reported in detail in the peer reviewed literature in 2000 (Noldus, Trienes, Hendriksen, Jansen & Jansen, 2000) and case studies compiled jointly by the researchers and the system manufacturers can be found at www.noldus.com. Topics include analysis of musculoskeletal disorder risk factors in ship maintenance (Van Wendel de Joode, Verspuy & Burdorf, 2004), and manual handling in the rail transport

sector (Houting, Van Eijsden & Rensink, 2004). In all those cases reported for human studies however, the system was not used to analyse current streams of physiological data as well as observed behavioural / task data. There are as yet few critical assessments of the Observer tool for ergonomics applications (Baber, 1994; Li & Buckle, 1999)

The US Army appears to be investing heavily in simulator-based training as part of their Future Force Warrior programme (Warwick, Archer, Brockett & McDermott, 2005); however, this review was unable to find any recent public domain material on the collection and use of relevant operational data of the type discussed by military researchers. It seems likely that given their commitment through this programme to improving 'organic tactical intelligence collection assets, enhanced situational understanding, embedded training, [and] on-the-move planning' they would also be evaluating the effectiveness of their interventions through real-time monitoring of some description.

2.3 The collection of integrated data

Multi-channel

Alexander (2003) made a call for greater efforts in the ergonomics / human factors aspects of rural fighting. "I personally believe that it is time that we seek out the assistance of those specialists in the humanities and social sciences." He adds, "we need to understand why we do the things we do." This, he suggests is because "It could be argued that the technical/scientific side of predicting fire behaviour has reached a limit and that further major advances and the greatest gains with respect to improving fire safety from a fire behaviour standpoint are likely to be made by how this information is applied by the user (i.e., the human aspect). This includes a wide spectrum from the lay public to the individual firefighter to the fire behaviour officer/analyst to the incident commander to the line or resource officer".

Physiological studies to assess the workload changes brought about by new equipment and clothing ensembles are of course just part of the process of judging suitability. The reasons for an increase in workload following manipulation of equipment or procedural variables however will probably not be understandable simply from analysing patterns of total energy expenditure. Nor may simulated task studies reveal interactions that do in fact have significant bearings in operational conditions over protracted periods. To understand these important interactions other data streams including visual and verbal records are needed for analysis in conjunction with the physiological records.

The use of simultaneous multi-channel data methods also provides opportunities for triangulation in checking factors that can seriously diminish scientific rigour. Firefighter behaviour and events that could otherwise distort

findings, but go undetected, can be observed. Through concurrent video, it is possible to see individuals: riding on vehicles (would clearly distort activity monitor results), 'having a play' with testing equipment during breaks (a problem with some models of heart rate monitors), removing gear to adjust clothing layers, etc. The potential for discrediting of entire studies due to unexplainable corruptions of data are thereby minimised. It is far more likely with an integrated study that anomalies can be explained, and useful data therefore not discarded with bad.

2.4 Literature review conclusion

The literature on physiological workload in rural firefighting relates predominantly to simulated situations. From the literature it is clear that such data needs to be interpreted in the context of the firefighters actions. Increases in heart rate can occur for psychological reasons as well as in response to physical exertions for example, and so multiple concurrent data streams offering triangulation are highly advantageous. This is made all more so by the absence of the researcher/observer from the scene at real fires.

The concept of a methodology that combines task analysis, performance evaluation and physiological costs is therefore clearly an attractive one. Not only to provide overdue physiological field data specific to New Zealand conditions, but also begin the process of compiling real-time resources describing human behaviour and responses in the stressful, risky conditions (Putnam, 1996; Alexander & Thomas, 2003) of wildfire operations that can be used in training.

Existing studies could not be found describing the type of method proposed by COHFE in this research, although it is likely that the more advanced military research units are developing techniques along similar lines.

3. Methods

The methodology described below has been developed in-house and has stimulated much interest from overseas research organisations investigating work in demanding environments. The technology, although originally developed for New Zealand firefighter studies, has been successfully trialled in studies of tree fallers in logging operations. The system is able to collect up to 4 hours of uninterrupted video, heart rate, and Global Positioning System (GPS) data. To our knowledge we are the only research group that have such a mature data collection and analysis system.

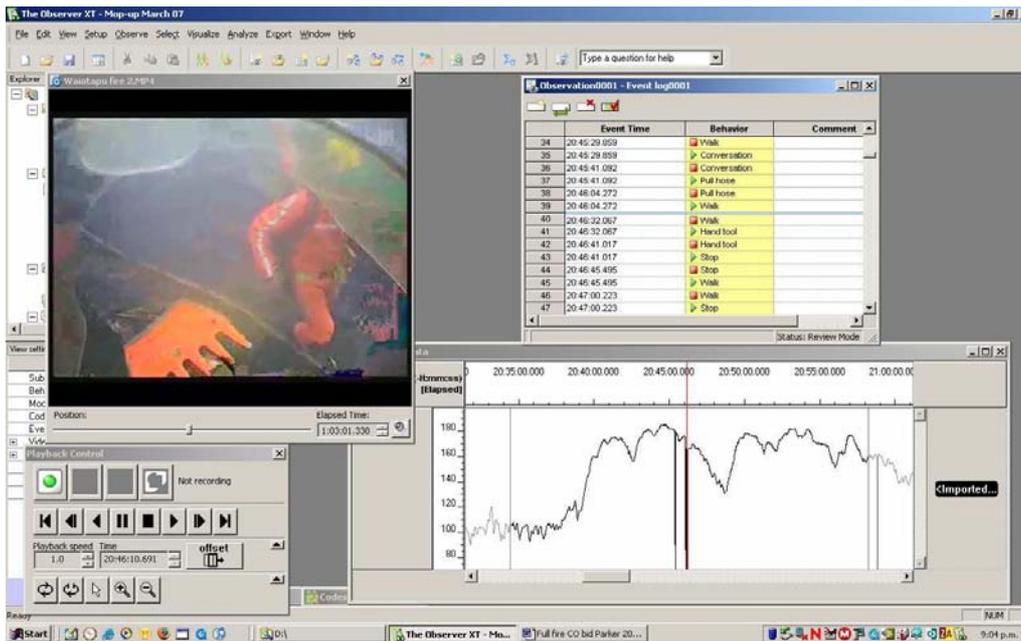
Video

The video footage was analysed using the Noldus Observer XT software. This enabled the researcher to easily synchronise (multiple) video files with data files for analysis. Also, the video footage was synchronised with the heart rate and GPS data to build up a picture of activities, work rates and movements of each firefighter. These were related to the fire and environmental variables to develop an understanding of how these factors influence firefighting 'productivity' in terms of effectiveness.

For video analysis the researcher assigned behaviours and events to keys on the computer keyboard. The video recording was a digital video file and the viewing of it was controlled from the keyboard/mouse. The researcher stopped, rewound and slowed the viewing and recorded the occurrence of the predefined actions, behaviours or events. These were captured by the software and simple information such as the number of occurrences of an event, or the proportion of time a person spent performing an activity were output.



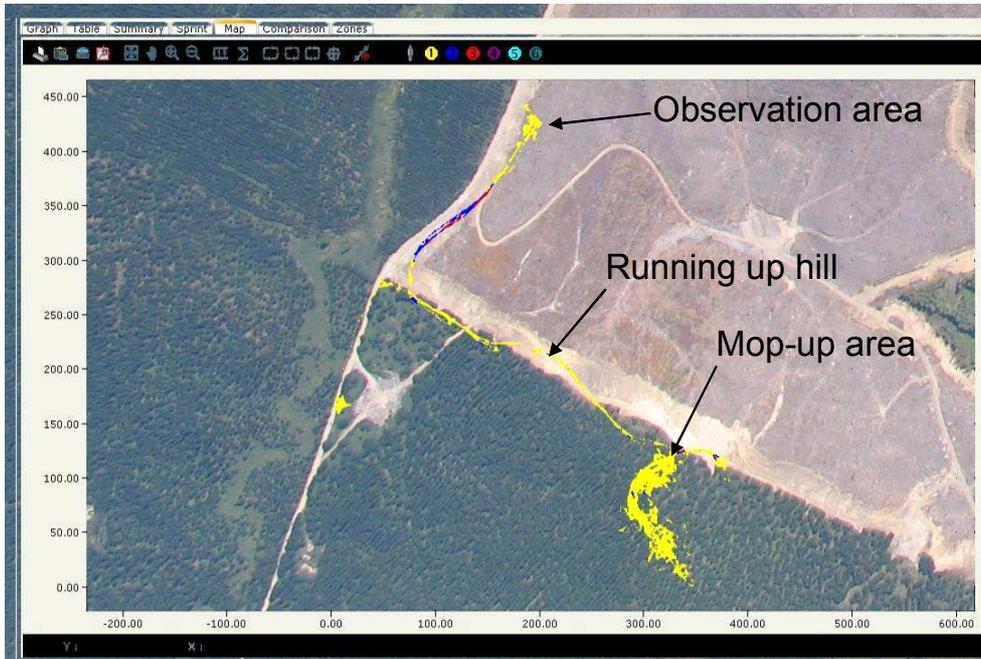
Data collection harness for rural fire fighter



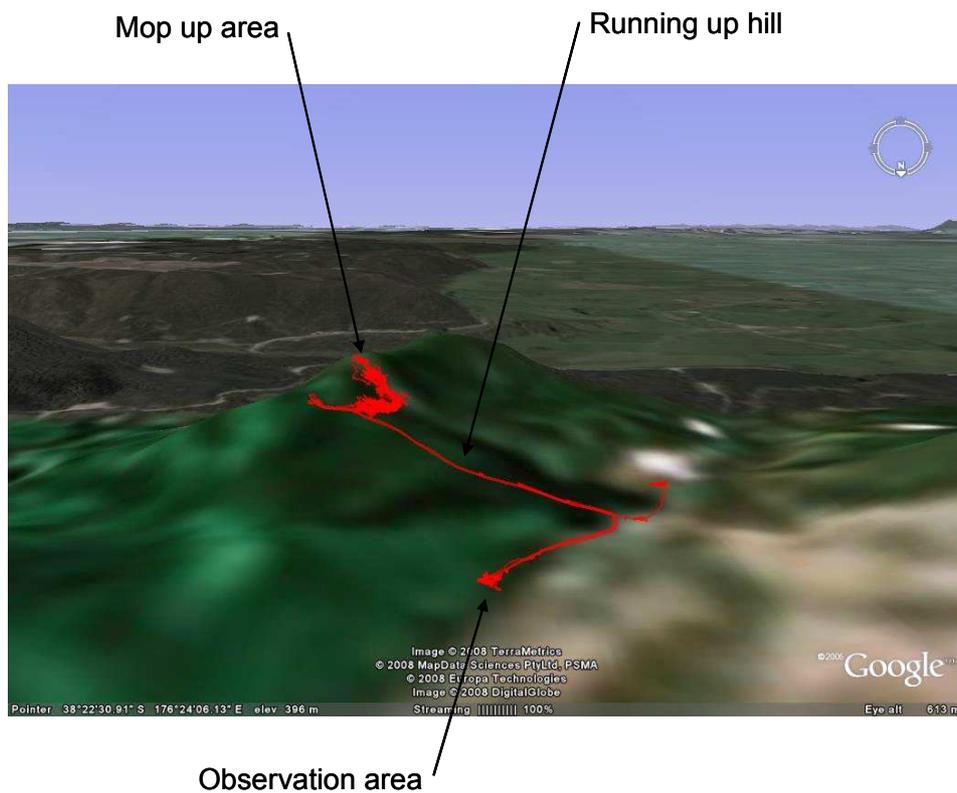
Synchronisation of video and heart rate data and task analysis on data input screen using data from real fire suppression

GPS and Heart Rate

Analysis of the data collected was performed using the associated GPSports GPS and heart rate analysis software and the Noldus Observer software. The latter enabled the data to be synchronised and combined with the video recording information for activity analysis.



Movement of firefighter generated from GPS data and overlaid on aerial photograph



GPS data was subsequently synchronised with Google Earth to provide oblique 3D representations of the terrain traversed by the firefighters during the recording period.

4. Results

The total number of usable data sets in this first year of data collection is less than hoped for, but the uptake of the study demands by crews has been far better than expected. Communication with other field based experimental scientists indicates that this is entirely consistent with this type of study – new technology being operated by personnel whose primary task is not data collection but firefighting. The data collection ensembles were worn to 11 fires and a total of 8 complete data sets were collected. In addition, 5 incomplete but useful data sets were collected. The opportunity arose to collect data at experimental burns in Australia and these have been identified and included in the data set.

Summary information on the data sets is presented below.

Datasets collected

Fire	Date	Activity				Location	Directory
1	20 March 2007	Water mop-up Laying hose	Video	HR	GPS	North Island	Wai
2	23 March 2008	Water mop-up with hose	Video	HR	GPS	North Island	Sala
3	21 March 2008	Tool mop-up	Video	HR	GPS	South Island	Hills
4	26 March 2007	Ignition	Video	HR	GPS	North Island	Kai
5	1 Feb 2008	Ignition	Video	HR	GPS	South Island	Card 1A
5	1 Feb 2008	Observation	Video	HR	GPS	South Island	Card 3A
5	1 Feb 2008	Observation	Video	HR	GPS	South Island	Card 4A
6	8 Feb 2008	Ignition	Video	HR	GPS	South Island	Card 2A
7	12 March 2008	Water Suppression	Video	HR	-	Australia	JP
8	11 March 2008	Water suppression	Video	-	-	Australia	Colgate
9	4 March	Water suppression	Video	-	-	Australia	Smoke Chaser
10	3 March 2008	Observer at experimental burns	Video	-	-	Australia	MC
11	4 March 2008	Observer at experimental burns	Video	-	-	Australia	JG

Summary of physiological and productivity data from complete data sets

Fire	North Island Mop - Up	North Island Hose	South Island Hand tool	North Island Ignition	South Island Ignition	South Island Observe
Period (hh:mm)	1:59	1:40	1:17	1:27	1:25	4:44
Distance travelled (m)	3160	1561	1998	3530	871	3568
Fire ground area (m ²)	1800	980	880	na	na	na
Average heart rate (bpm)	145	119	122	123	120	101
Maximum heart rate (bpm)	185	159	150	175	184	172
Minimum heart rate (bpm)	107	85	99	80	86	67
Age (years)	28	38	25	39	38	42
Terrain	Steep hill	Flat	Hill	Flat	Flat & steep	Flat & steep

5. Discussion

The methodology has proved robust, and dealt with the most significant technical and procedural barriers – that of gaining acceptance, and being usable by, workers in the field without scientific backup.

Secondly the collection of objective workload data during execution of the task in combination with task descriptive data provides an unparalleled opportunity to begin to explore the decision-making processes at key times. The ultimate question is why poor decisions made sense to individuals at the time. This research provides a solid advance in the knowledge needed to answer that question.

The data collected so far has provided indicative workloads of fire ignition and mopping up tasks. To our knowledge there are no equivalent datasets collected anywhere in the world. The foundation work by Budd, *et al.* (numerous) was under controlled experimental burns. The data collected by Heil (2002) and Ruby *et al.*, (2002) at real fires did not include precise information about what tasks the firefighter was engaged in.

The following scale has been proposed by Rodahl (1989) to give estimates of workload from heart rate:

Heart rate (beats / minute)	Physiological workload
Less than 90	Light
90 – 110	Moderate
110 – 130	Heavy
130 – 150	Very heavy
150 -170	Extremely heavy

All tasks except observation of fire can be classified as “Heavy” resulting in average heart rates between 110 and 130 beats per minute (bpm). These results are similar to New Zealand forestry tasks where average heart rates between 115 and 130 bpm are common. Examination of detailed heart rate traces (found in the *Section 7 Detailed Data Sets* at the end of this report) indicated the intermittent nature of fire suppression tasks. To maintain a high average heart rate the firefighters take brief rests by changing tasks. The same cyclic work / rest strategy is used in forestry tasks

The firefighters covered remarkably long distances during the observation periods. None of the firefighters, on questioning, realised they covered so much terrain in the normal course of their work. In this respect firefighting differs from forestry tasks which remain more localised.

More detailed results relevant to individual fires are presented in *Section 7 Detailed data sets*. Because of the unique and exploratory nature of this study many of the results are better presented in a case study format.

Limitations of the study

There has been no measure of the work capacity of individuals taking part in the study. Work capacity is due to genetic factors such as the size and strength of the heart, size of lungs and blood volume for example. Also training increases work capacity and work capacity decreases with age. In the coming year estimates of work capacity will be determined with advice from a physician.

Further work

In the coming year work load during training exercises will be measured. Firefighters have indicated their willingness to wear the data collection ensemble to gain representative training workloads. They can then be compared with actual workloads at fires. Firefighters taking part in the the Department of Conservation Pack Test will also be instrumented to collect data which can be compared with data collected at real fires. This will be of direct relevance to fitness requirements.

Verbal communication styles and protocols have not been examined in this study. Voice recordings have been collected but we have not requested ethical approval for their use in subsequent studies of communication style. With appropriate approval and consent of the firefighters we could examine the information flow on the fireground.

We are investigating a more reliable heart rate monitor for future studies. At times heart rate recordings were lost due to radio interference with the heart rate recorder or some unknown electrical artefact.

6 Conclusions

The project objectives were:

1. Measure the actual physiological workload and productivity associated with rural firefighting tasks under New Zealand conditions at real fires.
2. Relate measured workload and productivity for firefighting tasks to fitness and productivity requirements.
3. Provide input to guidelines for fatigue recommendations and productivity standards.

The study to date has been successful in that physiological workload data and productivity data have been collected at real fires. This is the first time such data has been collected. However the number of fires where data was collected was fewer than anticipated. The second year of data collection is expected to go more smoothly with a greater pool of knowledgeable firefighters available to operate the equipment.

Firefighters and authorities are willing to wear the data collection ensemble during training so we can better relate fitness and training to real fire requirements.

With a larger pool of data more reliable productivity measures will be developed.

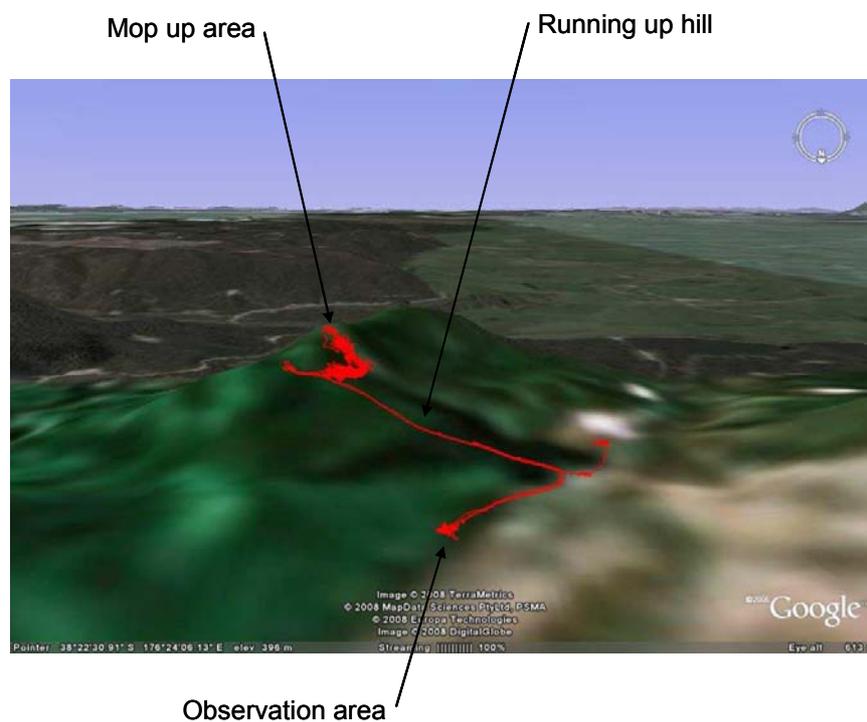
An unanticipated but valuable application of collecting the video data at fires is that it provides excellent training material. Firefighters and their parent organisations: forest companies, Department of Conservation, City and Regional Councils have expressed interest in obtaining copies of video to use in training programmes.

We have developed a method, using Google Earth, to present the path of the firefighter in a 3D terrain model. This allows for a much greater understanding of physical environment in which fire are fought in New Zealand.

7. Detailed data sets

1. Water mop-up & other tasks

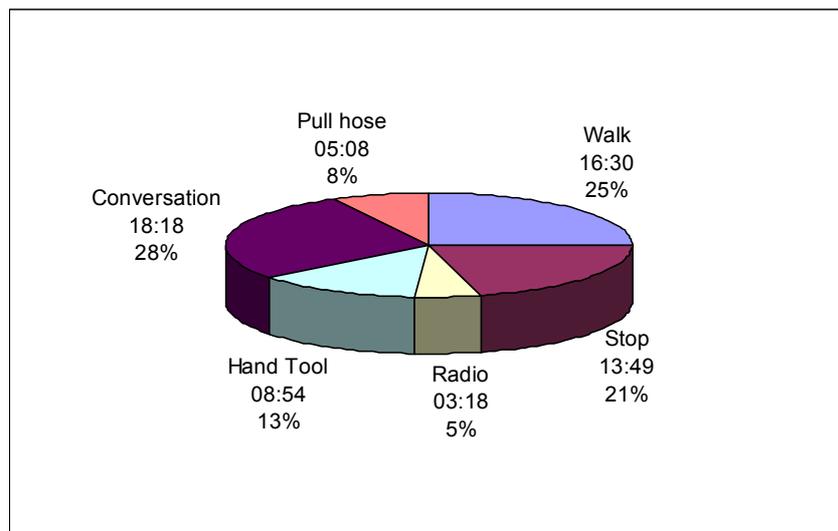
- At controlled burn.
- Observing fire then there was a spill-over into young radiata trees.
- The firefighter wearing the data collection ensemble coordinated other firefighters and provided support by delivering and moving hoses and using hand tools in mop-up.



Oblique view from the North of fire area with the path of the firefighter indexed to a Google Earth terrain model

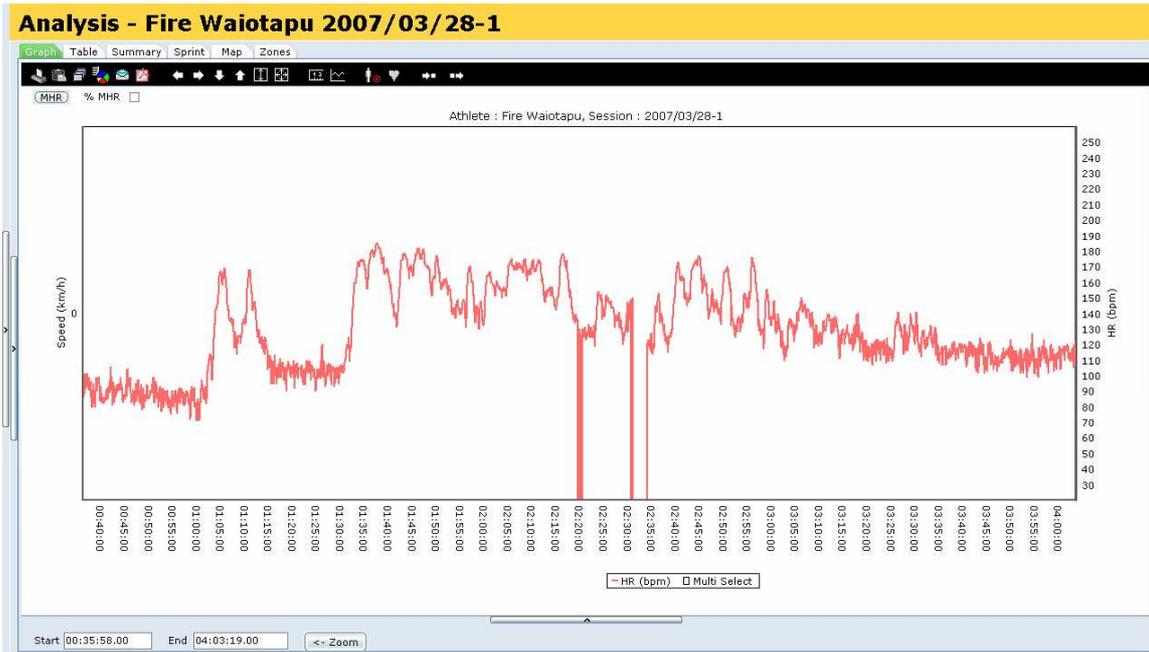


Screen capture of scene from the helmet mounted video

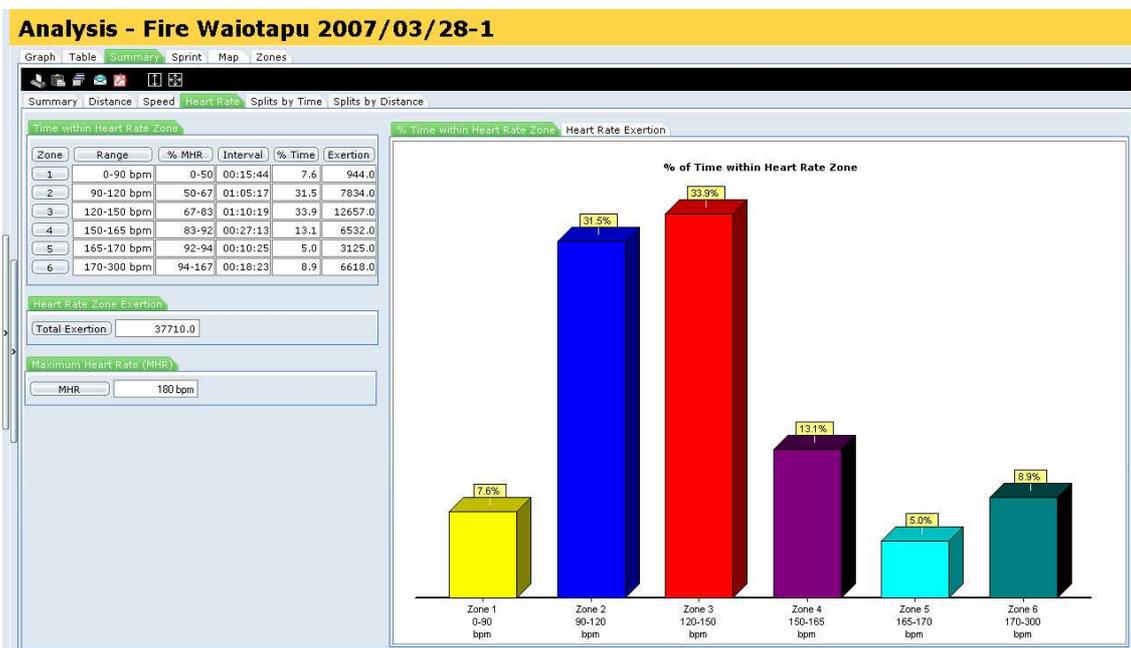


Actual (mm:ss) and proportion of time firefighter engaged in tasks during observation period

The firefighter was observed for a total of 3 hours and 20 minutes. However detailed analysis was available for one hour of activity. (This was the first video file collected and was in a non-compatible format with the task analysis software used in the study.) He spent 28% of the study period engaged in face to face conversation with other firefighters. All conversations were related to obtaining and relaying information related to fire suppression.

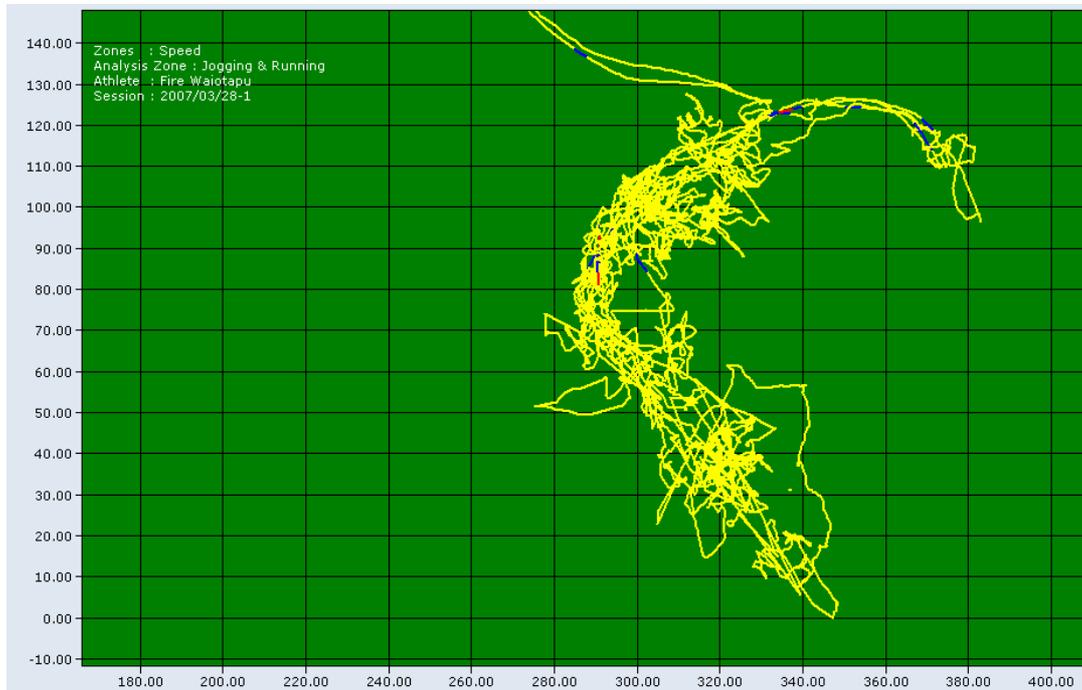


Heart rate over the entire period of data capture. The low heart rate at the beginning of the study period indicates a period of relative inactivity while watching the burnoff being ignited. After spill-over of the fire the firefighter's heart rate was elevated for extended periods.



Heart rate distribution of the fire fighter over the entire period of data capture. For a significant period of time heart rate was in the relatively low range of 90 to 120 bpm.

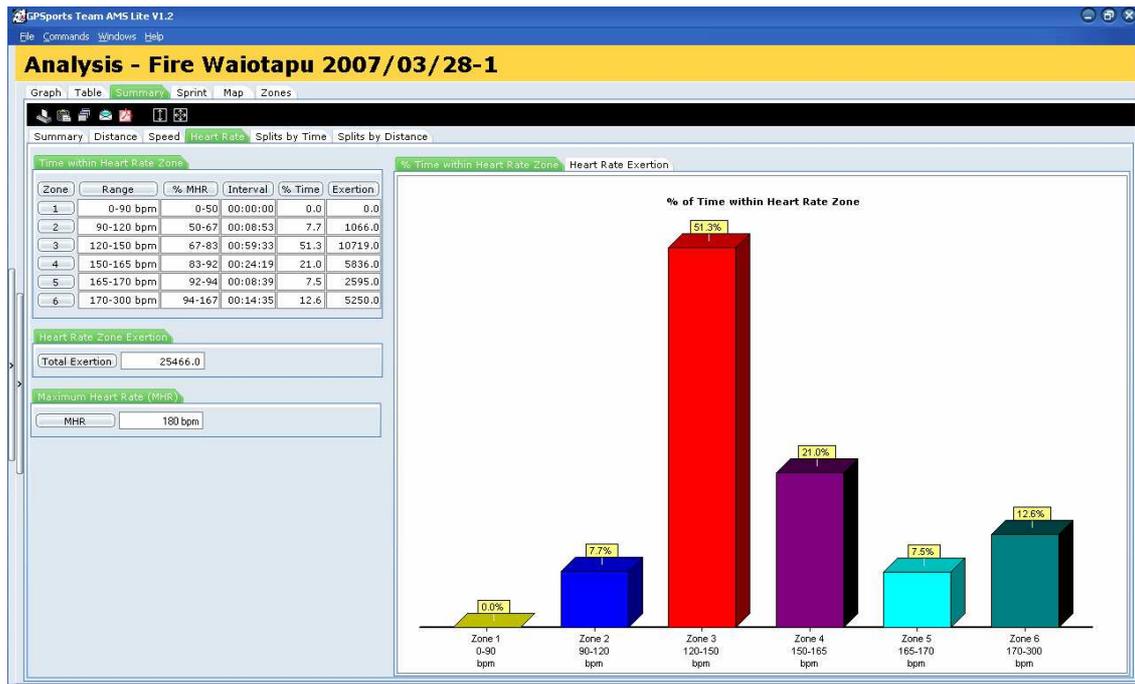
The period when the firefighter was on the actual area burnt was determined from the GPS data file. The corresponding heart rate and task data sets were extracted and used in the following analyses.



GPS generated map of the movements of the firefighter while on the fireground.

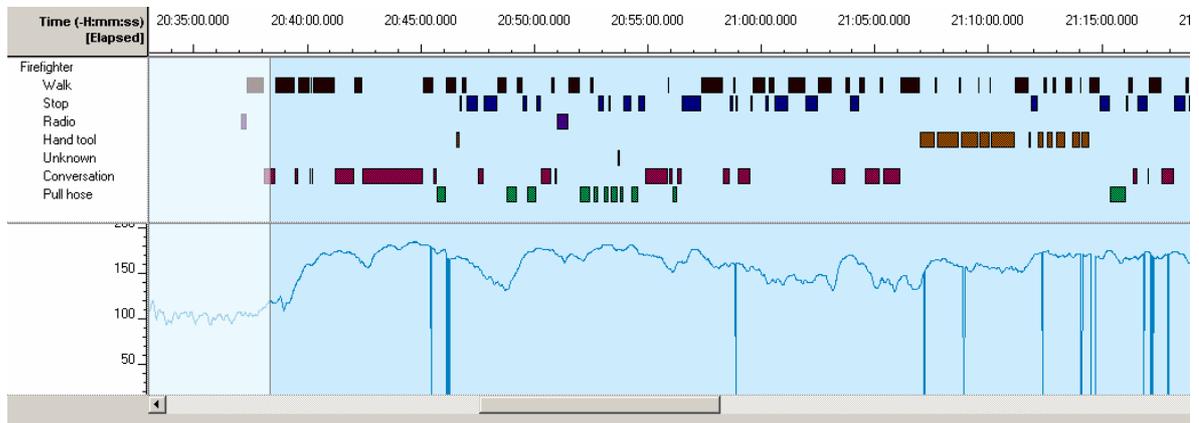
Productivity on the fireground

Period (hh:mm)	1:59
Distance travelled (m)	3160
Fire ground area (m ²)	1800
Average heart rate (bpm)	145
Maximum heart rate (bpm)	185
Minimum heart rate (bpm)	107



Heart rate distribution during the period when the firefighter was on the fireground. Heart rate is very high for a significant period of the observation period.

Task analysis and corresponding heart rate



Detailed analysis of tasks was derived from video data. The analysis indicates the rapid changes in activity of the firefighter throughout the study period.

2. Water mop up Sala St

Arson in manuka and gorse.

Deep duff which required large volumes of water to suppress.



Oblique view from the South of the fire area with the path of the firefighter indexed to a Google Earth terrain model



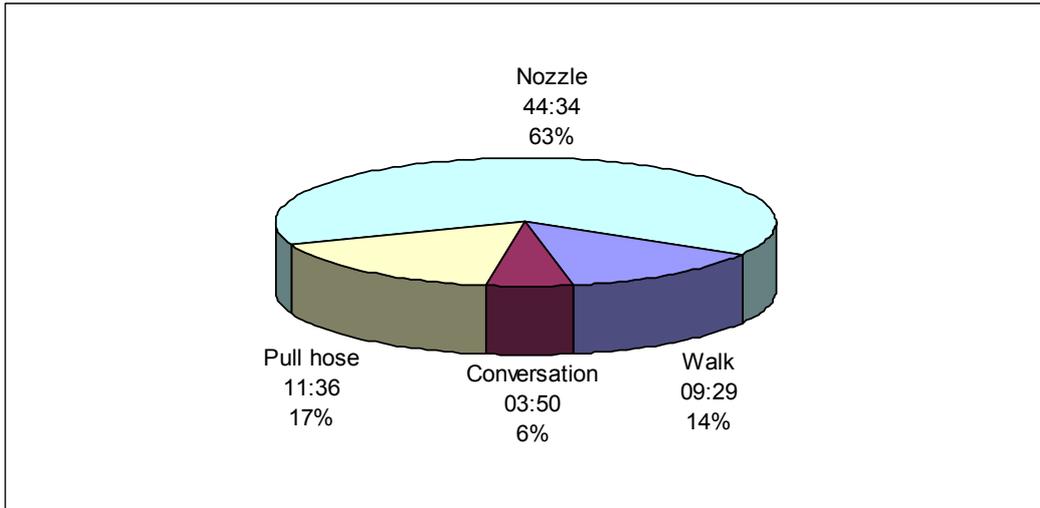
Ground view of the fire area



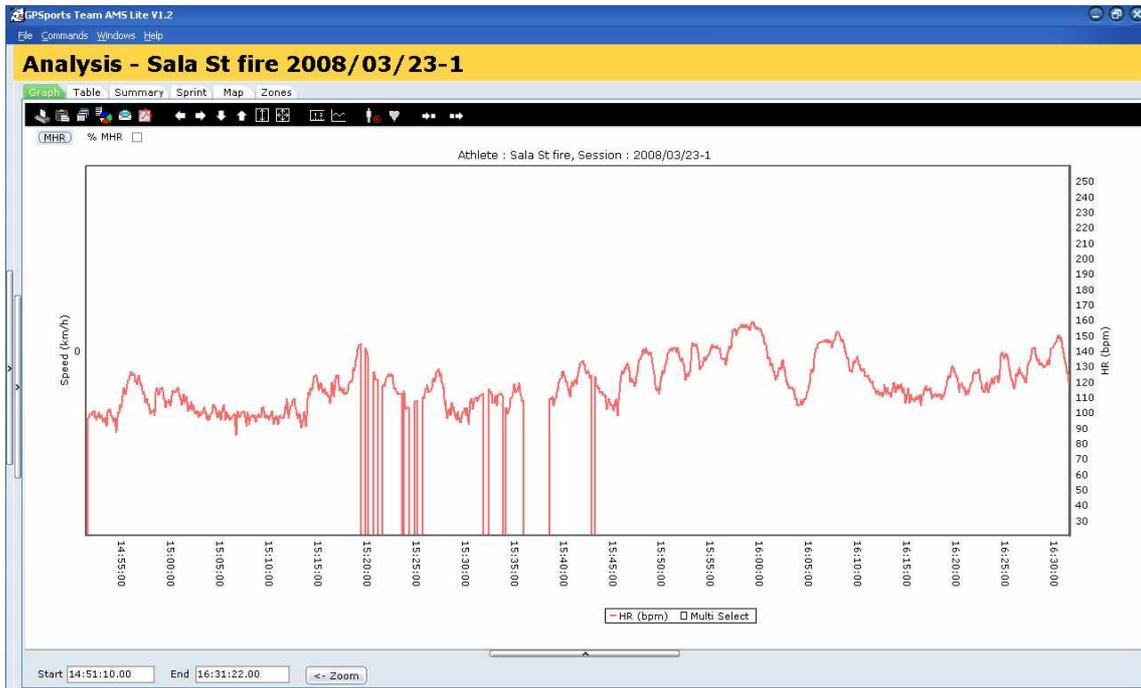
Firefighter wearing data collection ensemble and mopping up with hose



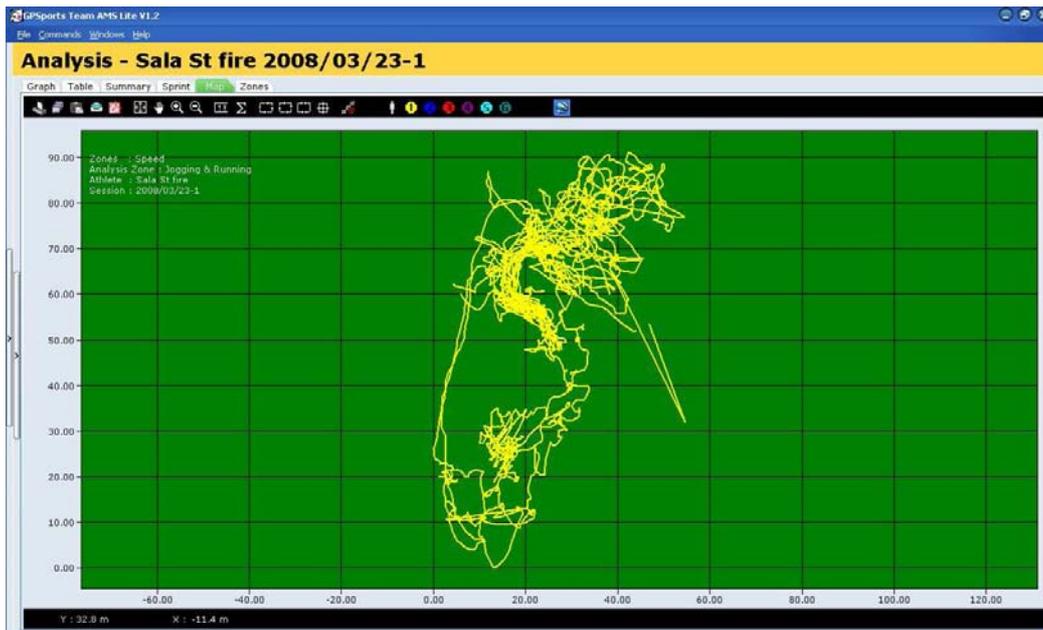
Screen capture of scene from the helmet mounted video



The firefighter was observed for a total of 1 hour and 40 minutes. He spent 63% of the study period at the nozzle of the hose applying water to the thick duff. For 17% of the observation period he tended the hose for another firefighter who was applying water. Little time was spent in conversation with other firefighters.



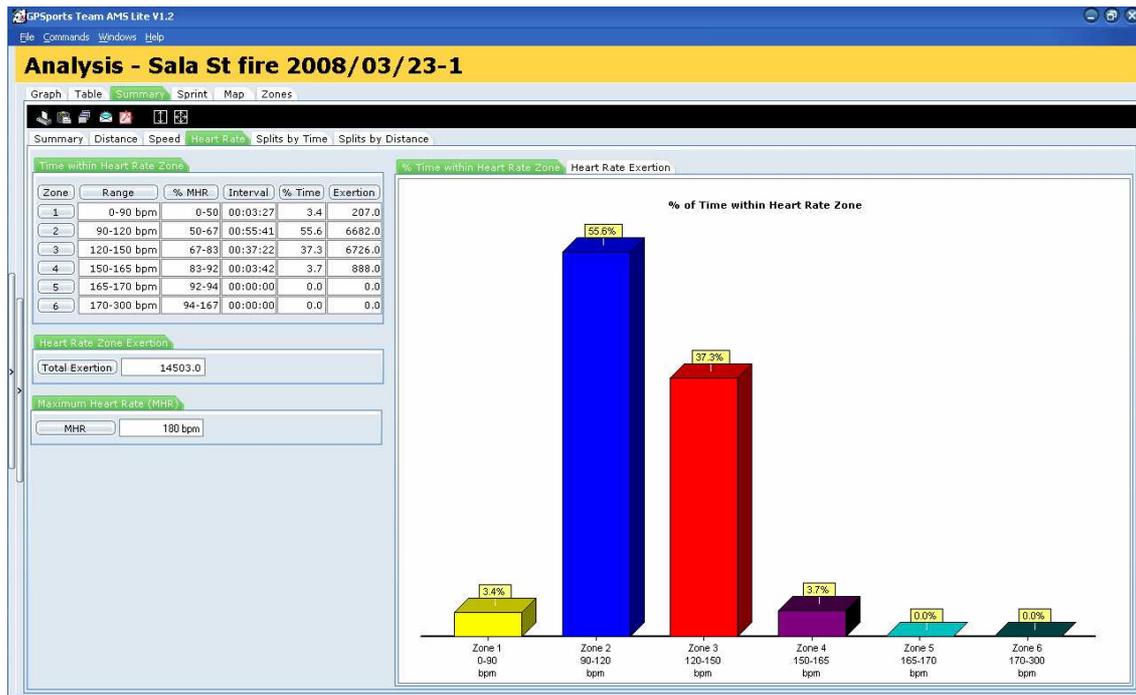
Overall the firefighters heart rate climbed as he became more fatigued later in the work period. Peaks in heart rate were associated with the application of water from the nozzle when the firefighter had to keep control of the hose.



GPS generated map of the movements of the firefighter during the study period

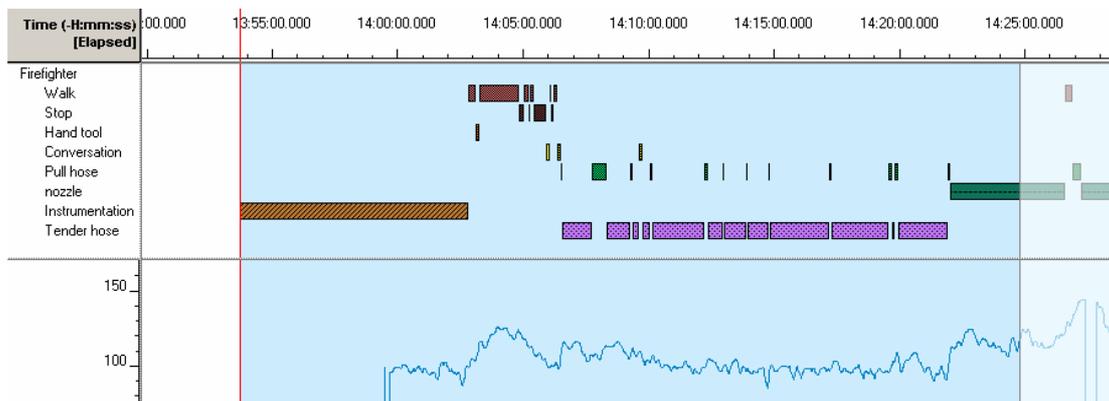
Productivity on the fireground

Period (hh:mm)	1:40
Distance travelled (m)	1561
Fire ground area (m ²)	980
Average heart rate (bpm)	119
Maximum heart rate (bpm)	159
Minimum heart rate (bpm)	85



Heart rate distribution during the period when the firefighter was on the fireground. The firefighter was able to limit the periods of high heart rate by resting while tending the hose.

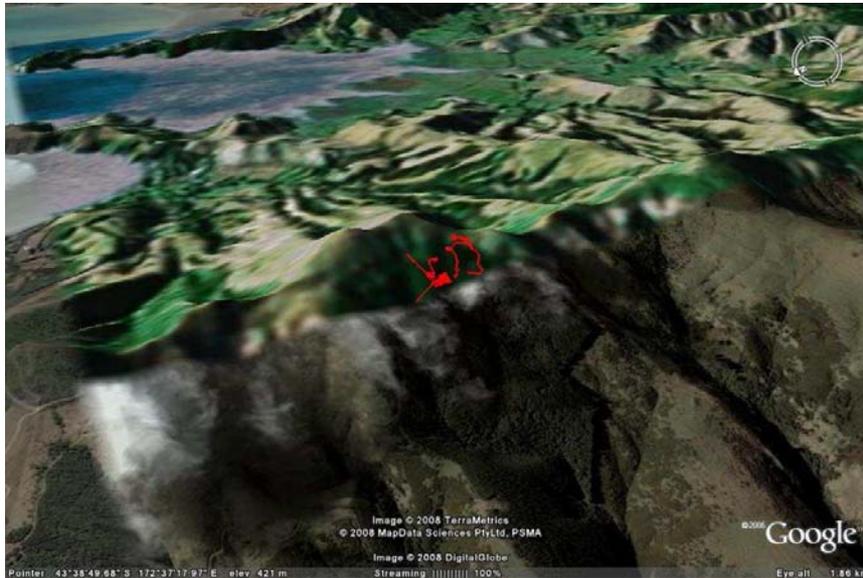
Task analysis and corresponding heart rate



The firefighter was engaged in two main activities – tending the hose and applying water at the nozzle. Applying water was the most physically demanding task.

3. Hand tool mop up

Burn in unpruned, unthinned 25 year old pine plantation after car set on fire. Fiefighter was mopping up with a McCloud tool.



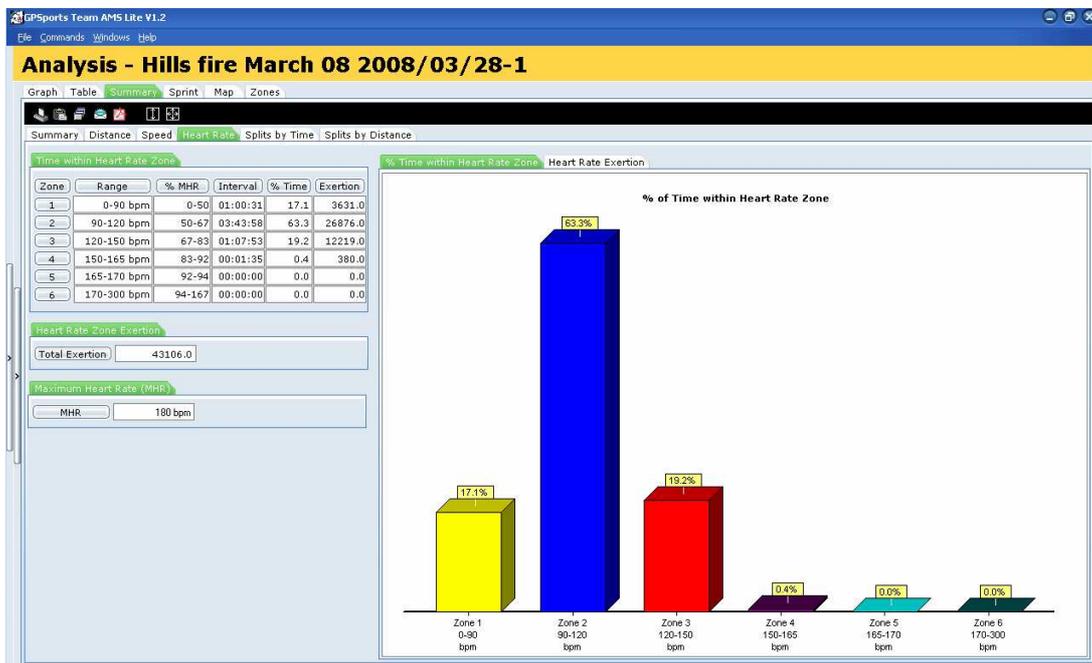
Oblique view of fire area from the North - East



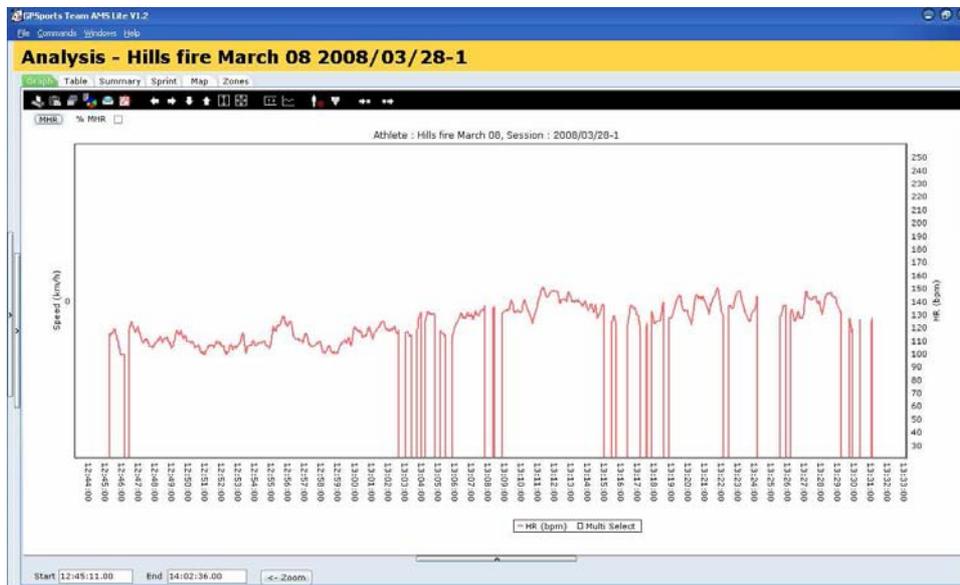
Closer view of the fire area. Poor aerial photographs exist in Google Earth for the region where the fire occurred.



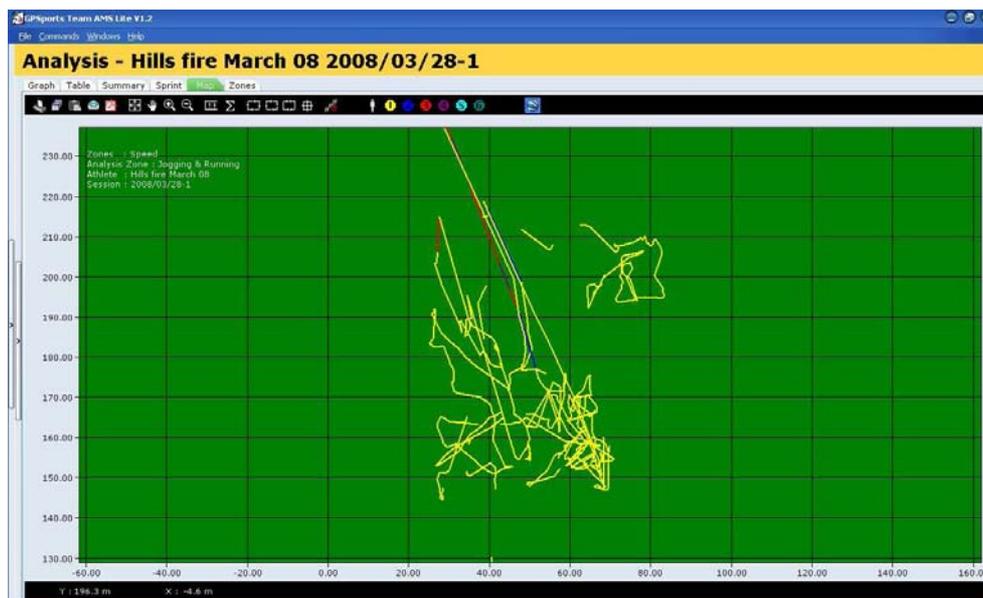
Screen capture of scene from the helmet mounted video



Heart rate distribution for the entire period of observation. The firefighter was able to rest and reduce the period of high heart rate. For 63% of the time his heart rate was between 90 and 120 beats per minute.



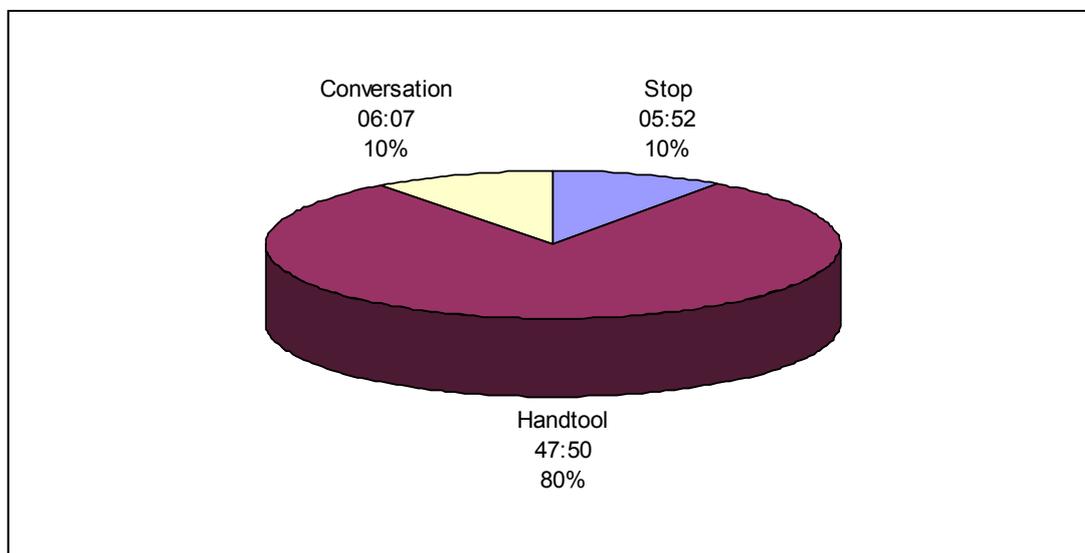
The firefighter's heart rate increased throughout the observation period indicating accumulated fatigue. However the heart rate monitor did not record the firefighter's heart rate signal later in the observation period. We are investigating a more reliable heart rate monitor.



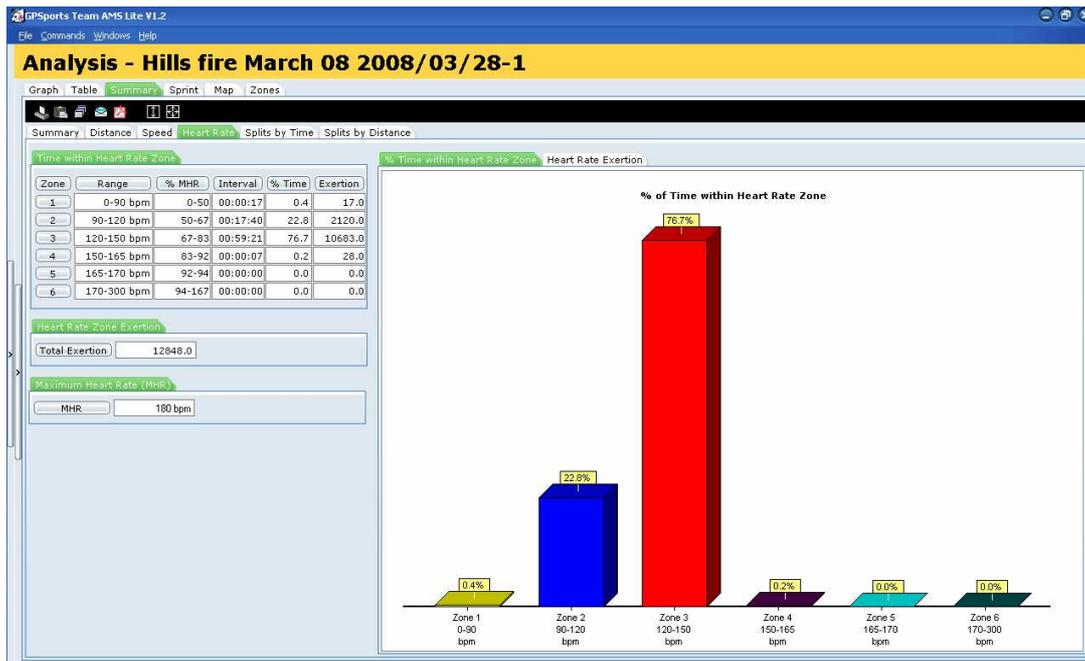
GPS generated map of the movements of the firefighter during the study period. Gaps in the yellow trace are due to loss of signal of the heart rate monitor / gps unit

Productivity on the fireground

Period (hh:mm)	1:17
Distance travelled (m)	1998
Fire ground area (m ²)	880
Average heart rate (bpm)	122
Maximum heart rate (bpm)	150
Minimum heart rate (bpm)	99

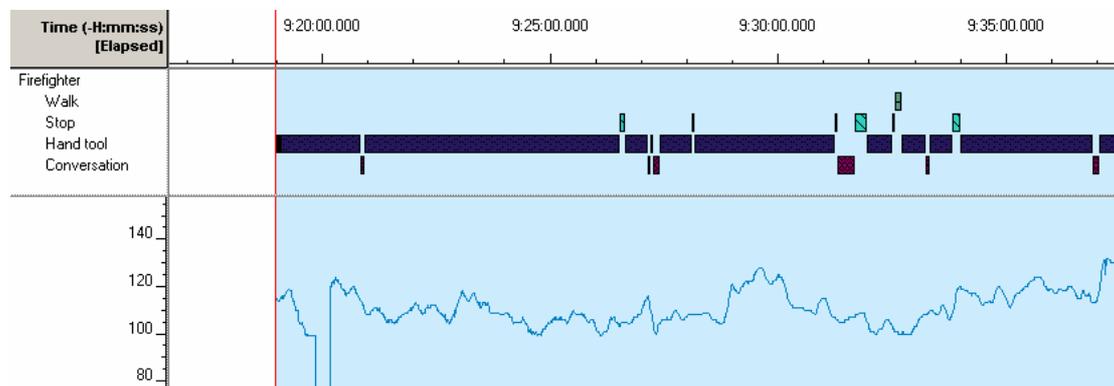


Period when the firefighter was actively engaged on the fireground. He spent little time engaged in conversation or resting.



Heart rate distribution of the firefighter while engaged in hand tool mop up. He was working at a high intensity of 120 to 150 bpm for 76% of the observation period.

Task analysis and corresponding heart rate



The firefighter was engaged in hand tool (McCloud) work throughout the study period. However his heart rate varied considerably reflecting pauses to rest for short periods of time.

4. Ignition

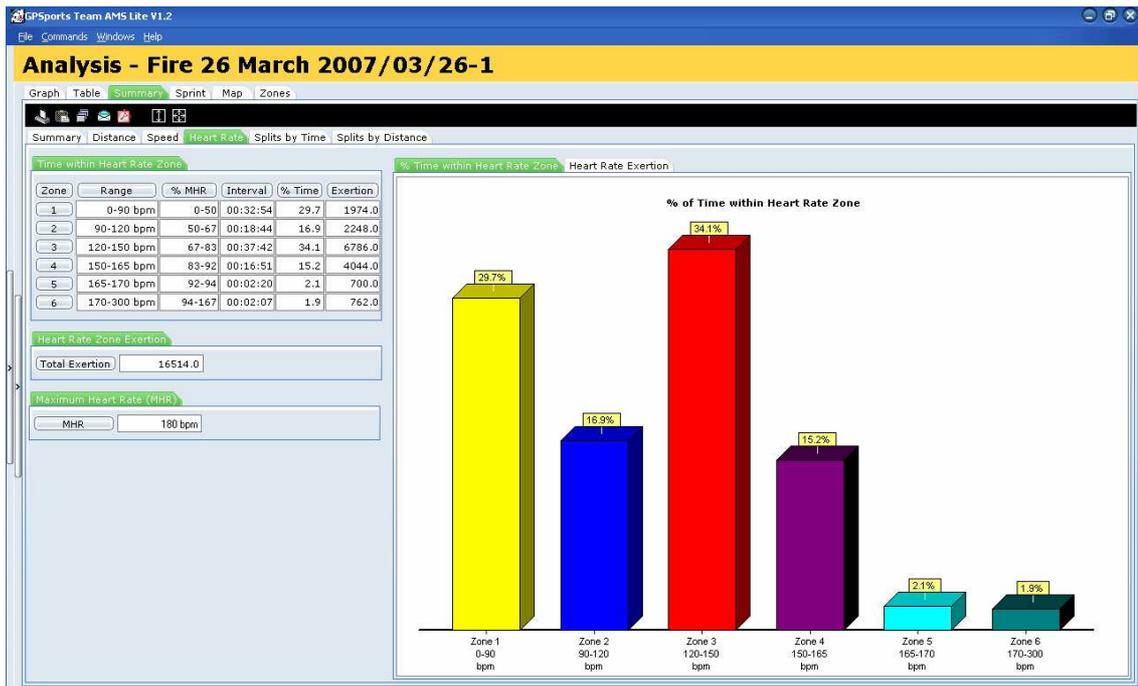
A backpack mounted flame thrower was used to ignite piles of logging debris.



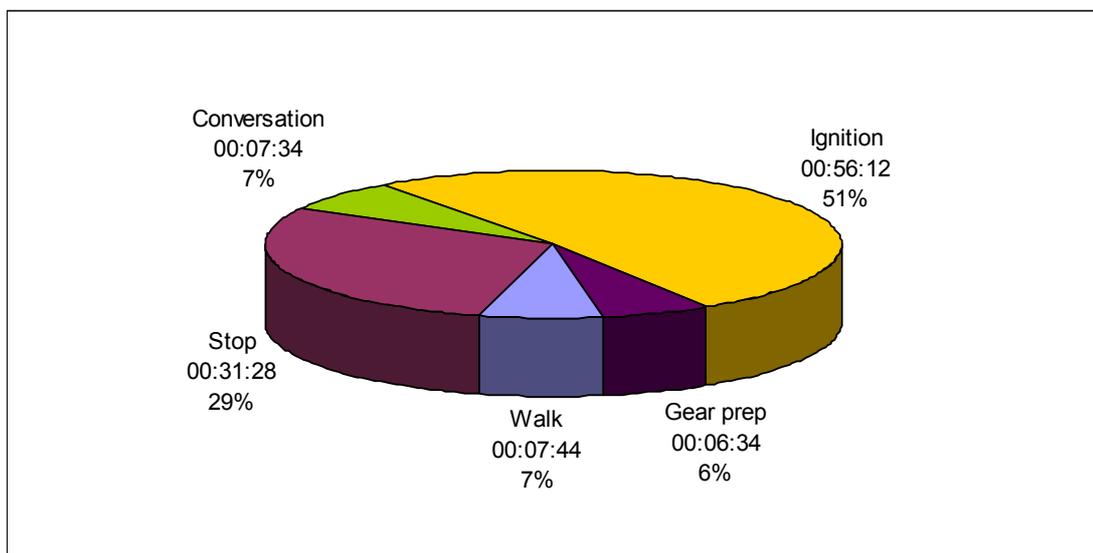
Oblique view of fire area from the South



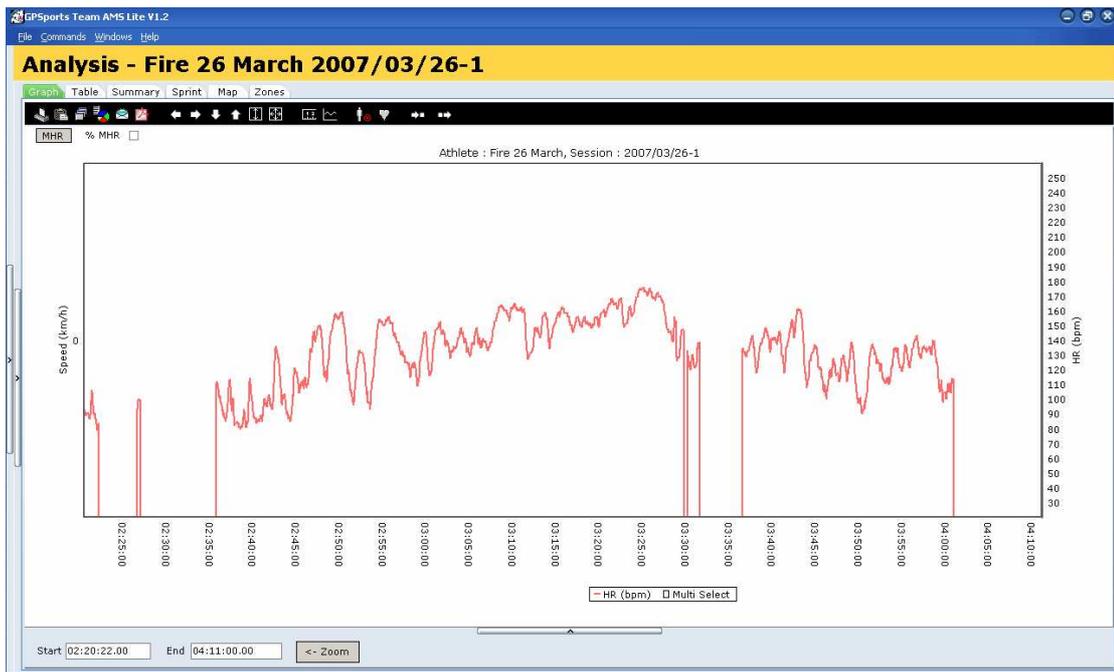
Screen capture of scene from the helmet mounted video showing flame thrower use in logging debris



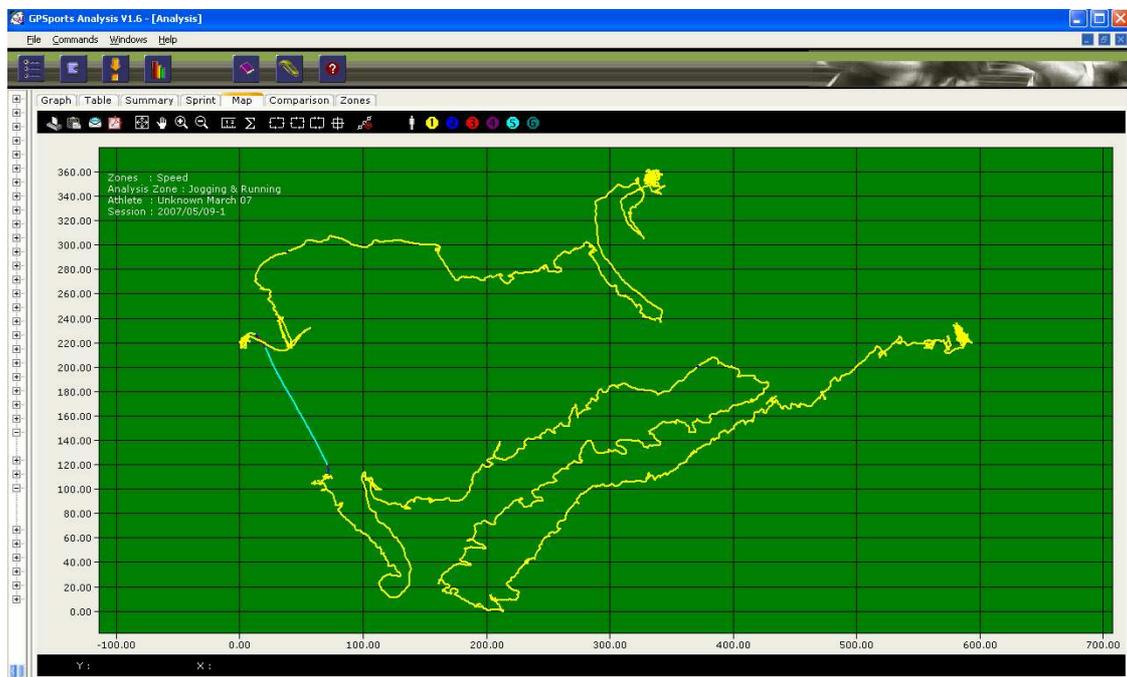
Heart rate distribution of the firefighter wearing a back pack mounted flame thrower. The firefighter had a long period of waiting before starting the ignition. This is reflected in the high proportion of low heart rate (30% of study period with heart rate below 90 beats per minute).



The firefighter was engaged in ignition for 51% of the observation period. During this time he was walking and spraying fire onto piles of logging debris.



The firefighter's heart rate rose while he was igniting piles of logging debris. During rest periods his heart rate would come back down.



GPS generated map of the movements of the firefighter during the study period. The firefighter walked along the piles of logging debris igniting them with a flamethrower. The pale blue line indicates high speed movement – when he rode in the back of a ute to the next pile of debris.

Productivity on the fireground

Period (hh:mm)	1:27
Distance travelled (m)	3368
Fire ground area (m ²)	-
Average heart rate (bpm)	123
Maximum heart rate (bpm)	175
Minimum heart rate (bpm)	80

5. Ignition and observation in high country

These data sets were collected as part of an experimental burn. The first data set is of a firefighter in the ignition crew lighting fire in the valley. The second data set is of a firefighter in an observation/suppression crew on the ridge.



Oblique view of fire area from the North – East. The red line on the ridge indicates the path of a firefighter observing the fire and waiting with suppression resources at the top of the burn area. The red line in the valley is the path of a firefighter with a back mounted flame thrower.

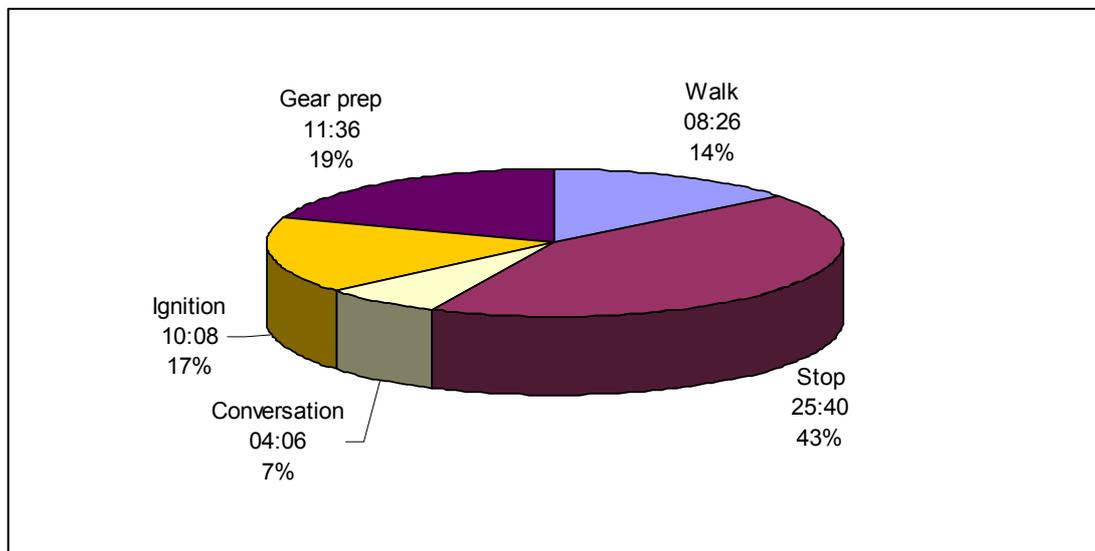


Closer view from the West looking along the ridge and down into the valley

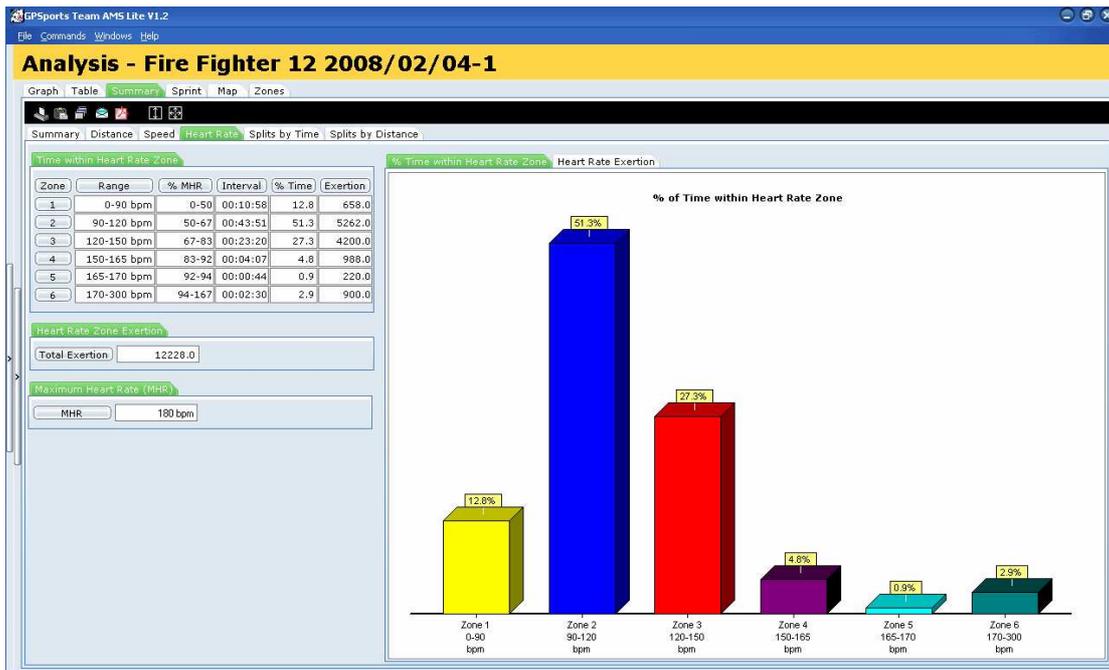
Ignition firefighter



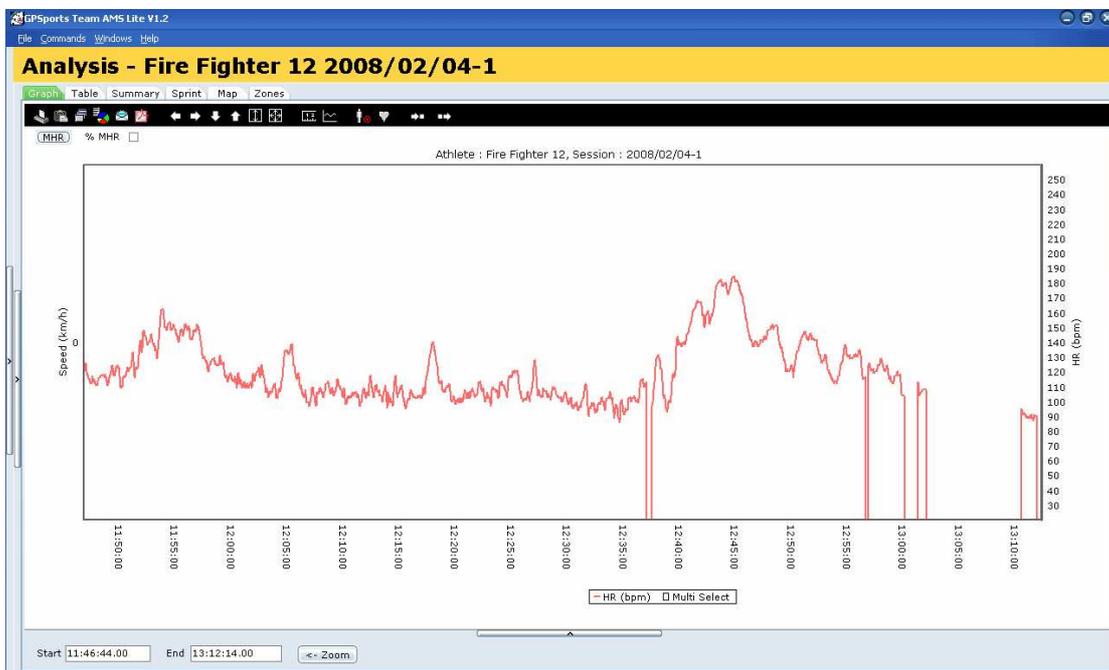
View from helmet mounted camera on firefighter wearing flame thrower



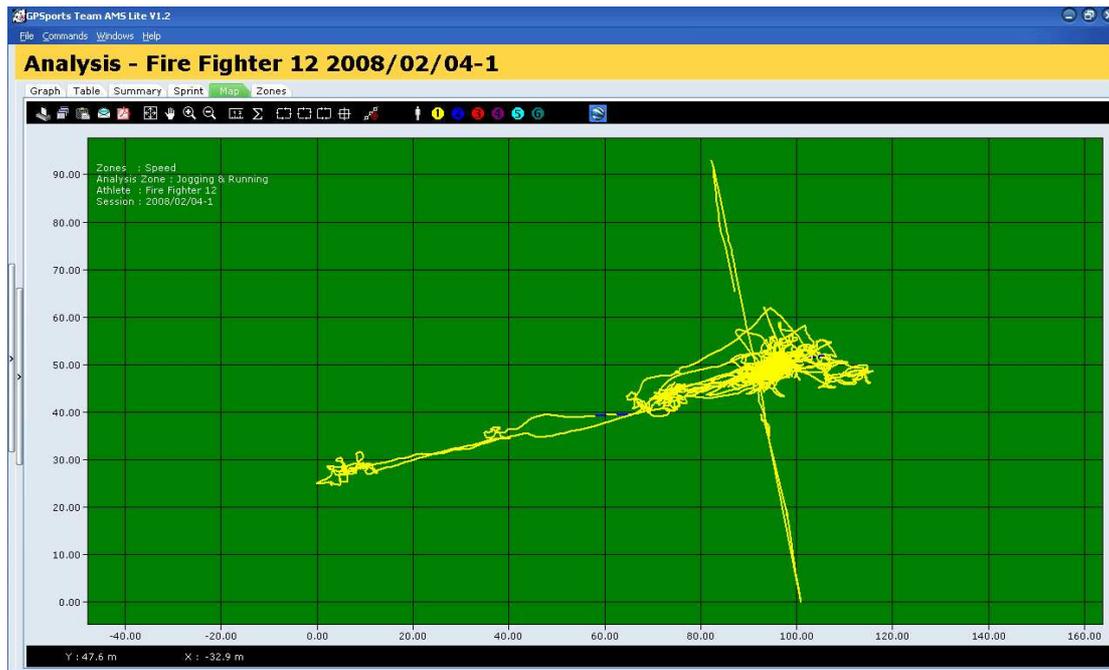
The ignition firefighter was subjected to a long period of waiting before flame throwing could occur. Ignition only occupied 17% of the observation period.



Overall, the ignition task was physically undemanding because of the long periods of inactivity. But once ignition was underway heart rate was elevated. For 36% of the study period heart rate was above 120 beats per minute.



The long period of waiting and brief periods of ignition are reflected in the heart rate trace of the firefighter.

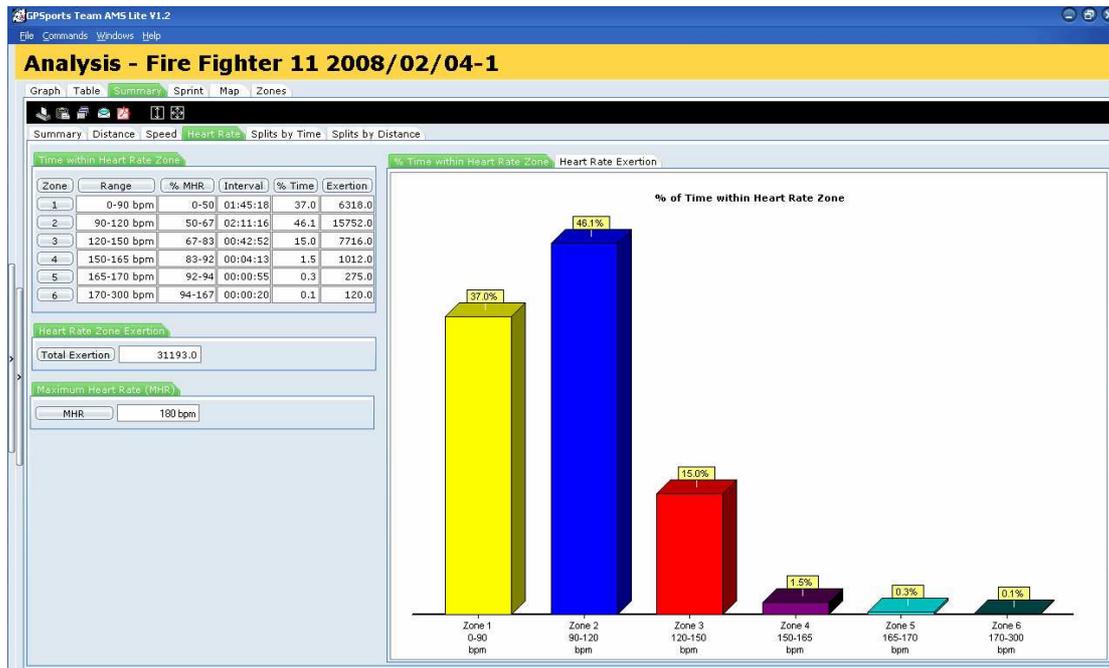


GPS generated map of the movements of the firefighter during the study period. The map gives an indication of distance travelled but the Google Earth representation gives a far better indication of where, in the terrain, the firefighter is moving.

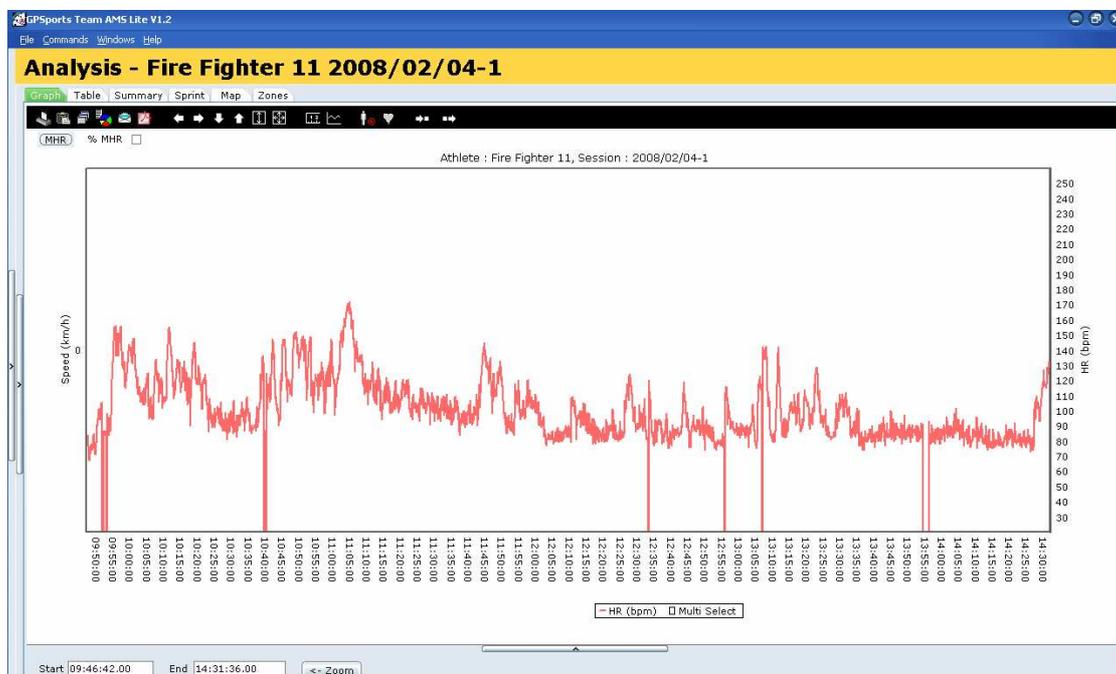
Productivity on the fire ground

Period (hh:mm)	1:25
Distance travelled (m)	871
Fire ground area (m ²)	-
Average heart rate (bpm)	120
Maximum heart rate (bpm)	184
Minimum heart rate (bpm)	86

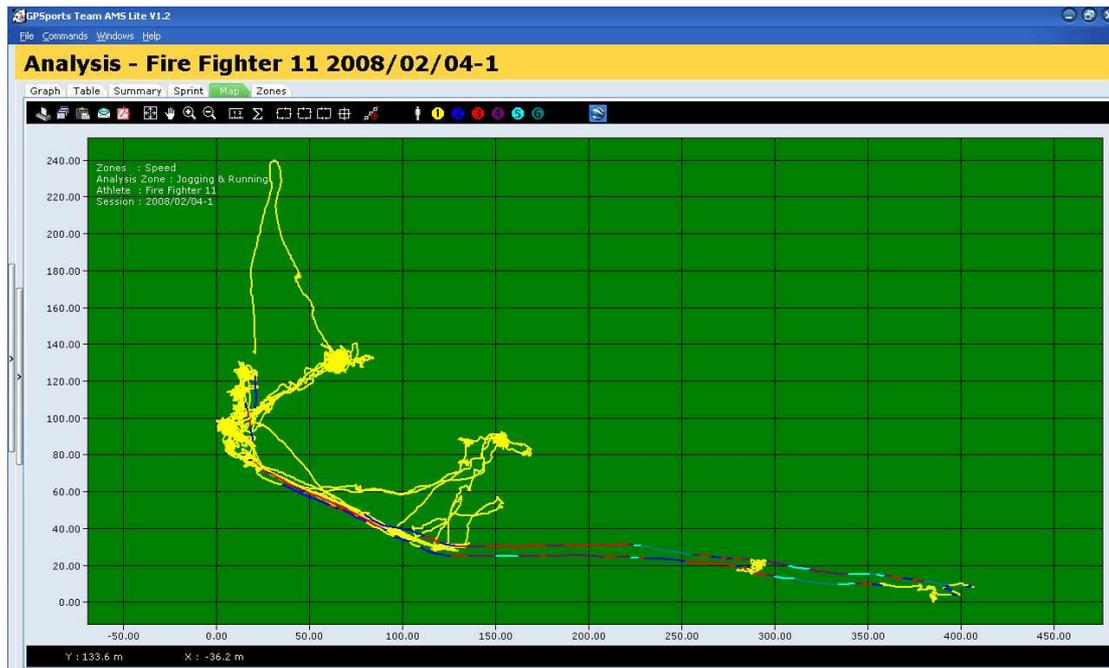
Firefighter on the ridge



Heart rate distribution indicates periods of light and medium activity. Heart rate was above 120 beats per minute for only 15% of the study period.



The firefighter had a period of strenuous activity to get to the observation area. Then occasional periods of activity interspersed with waiting.



GPS generated map of the movements of the firefighter during the study period. See the Google Earth overlay at the start of this section to see how the firefighter moved in the terrain.

Productivity on the fire ground

Period (hh:mm)	4:44
Distance travelled (m)	3568
Fire ground area (m ²)	-
Average heart rate (bpm)	101
Maximum heart rate (bpm)	172
Minimum heart rate (bpm)	67

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