The Environmental Impact of Fire

Final Report

Prepared by:

Drew Martin
Mai Tomida
Brian Meacham, Ph.D.
Worcester Polytechnic Institute
Worcester, MA

THE FIRE PROTECTION RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION RESEARCH FOUNDATION
ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02169-7471
E-MAIL: Foundation@NFPA.org
WEB: www.nfpa.org/Foundation

FOREWORD

Fires are adverse events with tangible costs for property and human life. Quantification of the immediate and direct costs of fire provide a metric for understanding the social and economic impact of fire and for assessing progress in fire prevention and protection. In addition to their most manifest physical costs, however, fires have a range of less immediate and obvious adverse consequences on the natural environment. These include air contamination from the fire plume (whose deposition is likely to subsequently include land and water contamination), contamination from water runoff containing toxic products, and other environmental discharges or releases from burned materials.

Current efforts to improve the sustainability of buildings focus on increasing energy efficiency and reducing the embodied carbon. This overlooks the fact that a fire event could reduce the overall sustainability of a building through the release of pollutants and the subsequent re-build. Several pieces of work exist on the quantification of the environmental impact of fire, but there is a need to pull this information together in a format suitable to be published in a mainstream technical publication and to identify the technical gaps that still exist. The Fire Protection Research Foundation initiated this project to compile and review the existing literature on the environmental impact of fire and document the knowledge gaps for future work.

The Research Foundation expresses gratitude to the report authors Drew Martin, Mai Tomida, and Brian Meacham of Worcester Polytechnic in Worcester, MA. The Research Foundation appreciates the guidance provided by the Project Technical Panelists and all others that contributed to this research effort. Special thanks are also expressed to the National Fire Protection Association (NFPA) for providing the project funding.

The content, opinions and conclusions contained in this report are solely those of the authors.

About the Fire Protection Research Foundation

The Fire Protection Research Foundation plans, manages, and communicates research on a broad range of fire safety issues in collaboration with scientists and laboratories around the world. The Foundation is an affiliate of NFPA.

About the National Fire Protection Association (NFPA)

NFPA is a worldwide leader in fire, electrical, building, and life safety. The mission of the international nonprofit organization founded in 1896 is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education. NFPA develops more than 300 codes and standards to minimize the possibility and effects of fire and other hazards. All NFPA codes and standards can be viewed at no cost at www.nfpa.org/freeaccess.

Keywords: environment, environmental impact, impact of fire on environment, impact of wildfire on environment

PROJECT TECHNICAL PANEL

Dave Butry, NIST

Janice Coen, National Center for Atmospheric Research

Ken Dungan, Risk Technologies LLC

Pravin Gandhi, UL

Chris Gallo, EPA

Kenan Ozekin, Water Research Foundation

Debbie Smith, BRE

Chris Wieczorek, FM Global

Ray Bizal, NFPA

Meghan Housewright, NFPA

Tracy Vecchiarelli, NFPA

SPONSOR

National Fire Protection Association (NFPA)

The Environmental Impact of Fire: Final Report

Submitted to the

Fire Protection Research Foundation

Submitted by

Drew Martin, Mai Tomida and Brian Meacham

Worcester Polytechnic Institute
Department of Fire Protection Engineering
50 Prescott Street
Worcester, MA 01609

1 May 2015

EXECUTIVE SUMMARY

While much research has been conducted regarding the cost of fire in terms of human life, property loss and business interruption, relatively little research has been conducted on the impact of fire on the natural environment. However, this topic is gaining new attention with global concerns associated with the impact on climate change resulting from carbon emissions: a by-product of most fires. In addition to carbon emissions, impacts can include non-carbon contamination of the air via the fire plume, contamination of soil and water from the deposition of products of combustion in the fire plume, contamination from firefighting water runoff containing toxic products, and other such environmental discharges or releases resulting from burned materials or otherwise released as a result of fire. This effort reviews existing research on the environmental impact of fire, including sources of contamination and associated effects, approaches to quantifying the impacts in terms of hazards, risks and cost – at a local level and at a regional level, identifies gaps in knowledge that are needed in order to make better assessments of the environmental impact of fire, and provides a conceptual framework for undertaking more comprehensive impact assessments once the needed data and information are available.

A review of literature related to environmental impact of fire was undertaken. As a starting point, the review considered sources two main themes:

a) Determining how 'environmental impacts' from fire is defined. This was needed to develop a working definition, or set of boundary conditions, for 'environmental impacts' of fire as related to the scope of this project. This was necessary to help better define the environmental impacts of concern, as well as to provide a basis for comparative analysis of the different environmental impact assessment methods used.
b) Review of fires with severe environmental effects. There have been several fires in recent history that have gained infamy because of their adverse environmental impacts. Identifying these fires provided examples as to the severity of impact from single fire events. The fires also offered the opportunity to see a documented approach to assessing the adverse impacts to the environment.

From this starting point, several sub-topic areas were identified as needing further study, including:

c) Identifying hazardous products from a fire.
d) Analytical techniques to quantify the environmental effects of fire
e) Transmission pathways for environmental stressors (hazards) to attack receptors (targets).

For the initial phase of this project we undertook a broad international literature search to gain an understanding of the work which has been previously conducted in the topic area. Currently the collection of source material has grown to more than 150 references, consisting of research papers, studies, and books. Appendix D: Bibliography of Relevant Literature contains the full bibliography.

From these sources, a smaller selection of documents was chosen for more detailed review. These were selected by filtering our bibliography by keyword, author, and organization. The sources whose title contained `impact assessment' were chosen, especially if they also referred to fire. Sources whose title also mentioned quantified data were also reviewed more closely. Lastly sources that looked at a specific type of analysis were also selected. *Appendix C: Review of Selected References* , contains the more detailed literature summary. The review includes the following topical areas.

- Fire statistics, which provide a picture of the fire problem. These were gathered from such sources as the NFPA, International Association of Fire and Rescue Service (CTIF), The Geneva Association, as

well as from a number of countries {Australia, Canada, Germany, Ireland, New Zealand, South Korea, UK, USA}.

- Impact assessment studies, which have been conducted for fires that have caused environmental damage. These include such events as the Sandoz fire and chemical spill in Basel, Switzerland, and the Sherwin William Paint Warehouse fire in Dayton, Ohio (USFA, 1987).
- Studies associated with sustainability and fire protection. FM Global (FM Global, 2010) completed a study showing the sustainability of sprinkler systems in residential buildings both in terms of water savings and limiting the effects of a fire. A similar study from BRE compared, using a life-cycle analysis, what the cost savings of installing and maintaining sprinklers is for small, medium, and large scale warehouses. Additionally, BRANZ considered what is important for sustainable construction, considering fire, and different techniques to limit the growth and spread of fire
- Research studies and papers on wildland fires and the environmental impacts that result. Wildland fires produce small particulates that can be very damaging to humans, especially those with any lung related health problems. Wildland fires are extensively studied not only for their immediate effects, but their long-term effects as well. Effects of burning out a portion of the forest range from increased erosion and problems for water quality to habitat degradation.
- Different techniques for quantifying the impact of fire from different products, with and without fire retardants. One of the most prominent is the "Fire-LCA", developed by SP in Sweden in the early 2000s (Andersson, et al., 2004). Hamzi et al. (2008) have done a significant amount of research to look at different products and quantify what the life cycle costs of the product would be if the product was to be impacted by a fire at any point over its life.
- Standards and guidelines. Of particular interest is the ISO Standard 26367, *Guidelines for Assessing the Adverse Environmental Impact of Fire Eff luents*. ISO 26367 Part 1, a published standard, providing an overview of the subject area, including describing fire effluents, what the environmental impacts of the fire effluents are, how intervention can be considered, and how to assess the overall environmental impact. ISO 26367 Part 2, currently at the Committee Document stage (unpublished and not publically available), will likely include details on toxic products of combustion and means to sample them in-situ, when published.

There are several limitations and bounding conditions associated with this study.

- One aim of this study was to investigate different approaches that have been undertaken for environmental impact analysis in other fields and whether they can be used to assess the impact of fire. To appropriately address the topic it was determined that it would be necessary to provide some discussion on the different ways that "environment" and "impacts" are defined. There are also several different reasons for conducting an environmental impact assessment.
- Another aim was to identify what types of impacts can be quantified as well as how they are quantified. It was found that there is often consideration of a wide range of impacts to a diverse biological spectrum, including people. It was also found that quantification can be local or global, species or system related, and narrowly or broadly encompassing. After initial investigation of the problem and discussion with the Project Panel, the scope was limited to ecological impact assessments, with human health impacts deemed out of scope. Also, while the topic of calculating the environmental impact of fire was identified as important, this effort describes how to go about quantifying the impacts, but does not include an explicit calculation method or examples.
- The types of materials produced during fires depend in large part on what is burning (e.g., vehicles, buildings and contents, vegetation). These materials are introduced to the environment through

several pathways through the air, water and soil. This is needed to identify compounds and materials which could have an impact to the environment.

- Although fires occur in buildings of all sizes, in nature, and in vehicles, it was decided to limit the research to wildland fires and to buildings of different use and scale, from residential occupancies to industrial facilities, with a particular emphasis on individual building / facility impact and not aggregate impacts (in the first instance), recognizing that there are challenges associated with contents of buildings, which are not always regulated by code and therefore the extent of impact not easy to determine (within the scope of this effort).
- With respect to buildings there are two aspects to the problem. The first is the combination of the building materials and contents, which have changed over time to include more synthetic plastic and textile materials (Kerber, 2010). The newer materials prove to be more flammable and toxic than natural materials. The second aspect is the addition of flame retardants to try to reduce the flammability of the contents. In recent years there have been several studies on the use of fire retardants. This research paper, in particular, did not include the effects of contents or fire retardants in its scope.
- Ultimately, it would be of interest to investigate not only the environmental impact of individual fires but how different sectors impact the environment in aggregate: locally, regionally and globally. In concept, one starts with assessment of a fire that occurs at a certain locality and scale. Once the fire occurs the environmental effects are measured in terms of the effect on the air, ground, and water. The effects are evaluated using expert systems. The evaluation of the effects is then used to determine the environmental impact in terms of ecology, environmental pollution, esthetics, and human interest. This can then be scaled for regional or other-scale effects by aggregating the impacts. While this effort does not get to this aggregate view, a potential path is provided.

This research has identified that a significant amount of information is available regarding the environment and the fire effects. However, the information is not complete, nor are the means to utilize that information in decision making. The following gaps have been identified, where additional knowledge and information could be researched in more depth and made available for decision makers.

1. Reporting/Study post fire event

From the beginning of the report several high profile fires with adverse environmental effects were described. For those fires, some information was able to be tracked down, but it was surprising how difficult it was. For most other fires, where concern for the environment was not considered there is little information. A reporting mechanism for fire departments to provide any feedback regarding the risk management of the fire during the event should be explored.

2. Process for EIA during construction

It is becoming common place for buildings to be constructed with some level of certification as to their sustainability, namely LEED in the United States. The building codes are catching up to this level of energy efficiency. It is recommended that an environmental impact assessment (EIA), which includes a fire event, be conducted.

3. Risk assessment tools for fire departments

There are some fire events which did have good environmental risk assessment done by the incident command, however there were also some fire events where better defined risk management techniques would have provided better guidance for the incident commanders. New tools and methods should be explored that provide fire departments with a clearer direction about which intervention technique(s) would be the most beneficial.

4. Exploring the impact of building contents

The contents of a building can change from year to year or even hour to hour depending on the occupancy. The contents of a building can make a difference when choosing a design fire for a space and it is seemingly similar for an environmental impact study. For example a large warehouse filled with bricks would be very different than a warehouse filled with fertilizer, herbicide, and other pesticides both in terms of the fire and that the environmental impacts would result. It is recommended that some sensitivity studies be conducted to determine the effect of contents beyond the studies from FM Global and BRE.

5. Exploring the impact of fire retardants

As building contents change to be more susceptible to fire, new fire retardants are being created to challenge the fire ignition and initial growth. It is recommended that a database of fire retardants and the products of combustion, when they are burned, is created to more fully understand their hazard and toxicity.

6. Detailed fire information for global fire problem

NFPA provides good records for the fire problem in the United States, as do many other countries, but it is difficult to find information regarding fires for the entire world. With the advance of sustainable design and rigid guidelines being developed there should be additional detailed records kept about the fire. The record keeping of fire events in other countries is most likely a political issue as well as a logistical issue, regardless options for expanding fire and environmental impact events should be explored.

In the end, this effort identified, summarized and compiled a large database of resources which help to define issues associated with characterizing the environmental impacts of fire. The outcomes of this effort can provide solid foundation for additional research in this area. The following outlines future research which could be of benefit in this area. Three major areas for future research are suggested, each aimed at providing environmental impact assessment tools for different stakeholder groups:

1. Decision tool for first responders
    - i) Quantified information about hazards
    - ii) Quantified information about contents
    - iii) Quantified information about fire extinguishing materials
    - iv) Risk management framework for quick/Easy analysis
    - v) Methodologies to report environmental impacts of fires
    - vi) Survey to determine, whether and to what extent first responders consider environmental impacts of fire
2. Decision tools for designers
    - i) Quantified information regarding hazards
    - ii) Tool describing differences of the environmental effects of one product undergoing combustion versus another product
    - iii) Survey to determine, whether and to what extent designers consider environmental impacts of fire
    - iv) Development of a decision tool incorporating quantified analysis techniques (LCA, CBA, RA) to compare the levels of fire protection at the design stage
3. Decision tool for policy makers
    - i) Information regarding aggregate fire problem
    - ii) Methods of gathering necessary data from the international community
    - iii) Comparative study of existing global regulatory frameworks
    - iv) Study to identify paths to incorporating fire in environmental policy

v) Survey to determine, whether and to what extent policy makers consider environmental impacts of fire
vi) Development of a decision tool incorporating quantified analysis techniques (LCA, CBA, RA) to compare the levels of fire protection at the building code/policy level

Prioritization of these efforts will depend on the goals and objectives of the responsible stakeholder groups. If the goal is to improve the environmental impact from first responders and the fire service then number one (1) should be undertaken to understand more fully the environmental impacts that the fire service contributes when attacking a fire and what possible changes they can make to reduce their environmental impact. Similarly fire protection designers can make a number of choices that affect the environmental impact of a building when considering if a fire does occur. There are numerous tools that exist to calculate the environmental footprint of a building and similar techniques could be used to account for the effects of fire. Number two (2) would involve exploring ways to incorporate the comparable sustainability between different types of fire protection measures. This could help answer questions as to what extent should sprinklers be implemented versus structural fire protection. The decision tool for policy makers described in number three (3) could be developed to understand the fire problem from a holistic viewpoint including the use of fire protection (preventive) and fire intervention (attack). To accomplish this an agreed way to calculate the aggregate effects of the fire would need to be established. A large concern with doing this currently is the lack of equivalent data from country to country. Another concern that needs to be addressed is which impacts are considered important and how to rank impacts that effect different parts of the environment, for different periods of time. If these can be resolved it is recommended that we determine an aggregate data set for comparison to other sources of environmental impacts as well as to get an accurate picture of the problem. Then ways to better incorporate prevention and intervention techniques could be implemented from a policy point of view.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This report has been prepared for the Fire Protection Research Foundation (FPRF) as the deliverable for the project *The Environmental Impact of Fire*. This part of the report overviews the background and context of the research. Sections 1.1 - 1.3 are reprinted from FPRF the call for proposals.

1.1. PROJECT STATEMENT

Fires are adverse events with tangible costs for property and human life. Quantification of the immediate and direct costs of fire provide a metric for understanding the social and economic impact of fire and for assessing progress in fire prevention and protection. In addition to their most manifest physical costs, however, fires have a range of less immediate and obvious adverse consequences on the natural environment. These include air contamination from the fire plume (whose deposition is likely to subsequently include land and water contamination), contamination from water runoff containing toxic products, and other environmental discharges or releases from burned materials.

Current efforts to improve the sustainability of buildings focus on increasing energy efficiency and reducing the embodied carbon. This overlooks the fact that a fire event could reduce the overall sustainability of a building through the release of pollutants and the subsequent re-build. Several pieces of work exist on the quantification of the environmental impact of fire, but there is a need to pull this information together in a format suitable to be published in a mainstream technical publication and to identify the technical gaps that still exist.

1.2. PROJECT GOAL

Develop a report and a publication that provides an overview of the existing literature on the environmental impact of fire and documents the knowledge gaps.

1.3. PROJECT TASKS

Task 1: Collect and analyze the relevant literature on the topic. The analysis should consider types of environmental impact, building types, wildland fire impacts, and risk versus hazard approaches.

Task 2: Conduct an assessment of key gaps in information reviewed in Task 1, in consideration of an overall environmental impact assessment of structure and wildland fires.

Task 3: Prepare a report on the findings from Task 1 and 2 and develop white paper suitable to be published in a mainstream technical publication.

1.4. SUPPLEMENTARY TASKS

In addition to the required tasks, several supplementary tasks aimed at clarifying and enhancing the project outcomes, were identified. Some of these tasks were included as part of the proposal, while others have resulted from the research which has been conducted.

- Define “environmental impact assessment” within the context of this study
- Develop a taxonomy to describe the broad range of environmental impact from fires
- Identify a list of toxic products resulting from a fire
- Point to the exposure pathways for toxic products to impact the fire
- Quantify the environmental costs of the fire in terms of loss of resources.
- Demonstrate first-order analytical approaches to the problem including benefit-cost analysis (BCA) and life cycle analysis (LCA).
- Develop a first order risk approach that qualitatively compares hazards of concerns and pathways that could be used as a decision tool for first responders.

1.5. APPROACH

Given that a significant outcome of this effort was to be a compilation and assessment of information related to environmental impact of fire, a literature review approach was taken. In brief, this involved using keyword searches to identify reports, studies and articles of interest, compilation of a database of resources, review of selected documents, assessment of state of knowledge, and identification of gaps in understanding of the issues and associated data, tools and methods necessary for assessing the environmental impact of fire.

Initially this review was conducted by studying sources related to:

a) Defining ‘environmental impacts’ from fire. The first step was to develop a working definition, or set of boundary conditions, for ‘environmental impacts’ of fire as related to the scope of this project. This was necessary to help better define the environmental impacts of concern, as well as to provide a basis for comparative analysis of the different environmental impact assessment methods used.
b) Reviewing fires with severe environmental effects. There have been several fires in recent history that have gained infamy because of their adverse environmental impacts. Identifying these fires provided examples as to the severity of impact from single fire events. The fires also offered the opportunity to see a documented approach to assessing the adverse impacts to the environment.

From this starting point, several sub-topic areas were identified as needing to be included in the study, including:

a) Identifying hazardous products from a fire.
b) Analytical techniques to quantify the environmental effects of fire
c) Transmission pathways for environmental stressors (hazards) to attack receptors (targets).

For the initial phase of this project we undertook a broad international literature search to gain an understanding of the work which has been previously conducted in the topic area. Currently the collection of source material has grown to more than 150 references, consisting of research papers, studies, and books. Appendix D: Bibliography of Relevant Literature, contains the full bibliography of our sources.

From these sources, a smaller selection of documents was chosen for more detailed review. These were selected by filtering our bibliography by keyword, author, and organization. The sources whose title contained `impact assessment’ were chosen, especially if they also referred to fire. Sources whose title also mentioned quantified data were also reviewed more closely. Lastly sources that looked at a specific type of analysis were also selected. *Appendix C: Review of Selected References* , contains the more detailed literature summary. The review includes the following topical areas.

Fire statistics, which provide a picture of the fire problem. These were gathered from such sources as the NFPA and the Center of Fire Statistics in Switzerland.

Impact assessment studies, which have been conducted for fires that have caused environmental damage. These include such events as the Sandoz fire and chemical spill in Basel, Switzerland, and the Sherwin William’s Paint Warehouse fire in Dayton, Ohio (USFA, 1987).

Studies associated with sustainability and fire protection. FM Global (FM Global, 2010) completed a study showing the sustainability of sprinkler systems in residential buildings both in terms of water savings and limiting the effects of a fire. A similar study from BRE compared, using a life-cycle analysis, what the cost savings of installing and maintaining sprinklers is for small, medium, and large scale warehouses. Additionally BRANZ considered what is important for sustainable construction, considering fire, and different techniques to limit the growth and spread of fire

Research studies and papers on wildland fires and the environmental impacts that result. Wildland fires produce small particulates that can be very damaging to humans, especially those with any lung related health problems. Wildland fires are extensively studied not only for their immediate effects, but their long-term effects as well. Effects of burning out a portion of the forest range from increased erosion and problems for water quality to habitat degradation.

Different techniques for quantifying the impact of fire from different products, with and without fire retardants. One of the most prominent is the "Fire-LCA", developed by SP in Sweden in the early 2000s (Andersson, et al., 2004). Hamzi has done a significant amount of research to look at different products and quantify what the life cycle costs of the product would be if the product was to be impacted by a fire at any point over its life (Hamzi, Londiche, & Bourmada, 2008).

Standards and guidelines. Of particular interest is the ISO Standard 26367, *Guidelines for Assessing the Adverse Environmental Impact of Fire Effluents*. ISO 26367 Part 1, a published standard, provides an overview of the subject area, including describing fire effluents, what the environmental impacts of the fire effluents are, how intervention can be considered, and how to assess the overall environmental impact. ISO 26367 Part 2, currently at the Committee Document stage (unpublished and not publically available), will likely include details on toxic products of combustion and means to sample them in-situ, when published.

1.6. BOUNDARIES / LIMITATIONS

One aim of this study was to investigate different approaches that have been undertaken for environmental impact analysis in other fields and whether they can be used to assess the impact of fire. To appropriately address the topic it was determined that it would be necessary to provide some discussion on the different ways that "environment" and "impacts" are defined. There are also several different reasons for conducting an environmental impact assessment.

Another aim was to identify what types of impacts can be quantified as well as how they are quantified. It was found that there is often consideration of a wide range of impacts to a diverse biological spectrum, including people. It was also found that quantification can be local or global, species or system related, and narrowly or broadly encompassing. After initial investigation of the problem and discussion with the Project Panel, the scope was limited to ecological impact assessments, with human health impacts deemed out of scope. Also, while the topic of calculating the environmental impact of fire was identified as important, this effort describes how to go about quantifying the impacts, but does not include an explicit calculation method or examples.

The types of materials produced during fires depend in large part on what is burning (e.g., vehicles, buildings and contents, vegetation). These materials are introduced to the environment through several pathways through the air, water and soil. This is needed to identify compounds and materials which could have an impact to the environment.

Although fires occur in buildings of all sizes, in nature, and in vehicles, it was decided to limit the research to wildland fires and to buildings of different use and scale, from residential occupancies to industrial facilities, with a particular emphasis on individual building / facility impact and not aggregate impacts (in the first instance), recognizing that there are challenges associated with contents of buildings, which are not always regulated by code and therefore the extent of impact not easy to determine (within the scope of this effort).

With respect to buildings there are two aspects to the problem. The first is the combination of the building materials and contents, which have changed over time to include more synthetic plastic and textile materials (Kerber, 2010). The newer materials prove to be more flammable and toxic than natural materials. The second aspect is the addition of flame retardants to try to reduce the flammability of the contents. In recent years there have been several studies on the use of fire retardants. This research paper, in particular, did not include the effects of contents or fire retardants in its scope.

Ultimately, it would be of interest to investigate not only the environmental impact of individual fires but how different sectors impact the environment in aggregate: locally, regionally and globally. The concept is illustrated in Figure 1. First a fire occurs at a certain locality and a certain scale. Once the fire occurs the environmental effects are measured in terms of the effect on the air, ground, and water. The effects are evaluated using expert systems. The evaluation of the effects is then used to determine the environmental impact in terms of ecology, environmental pollution, esthetics, and human interest. While this effort does not get to this aggregate view, a potential path is provided.

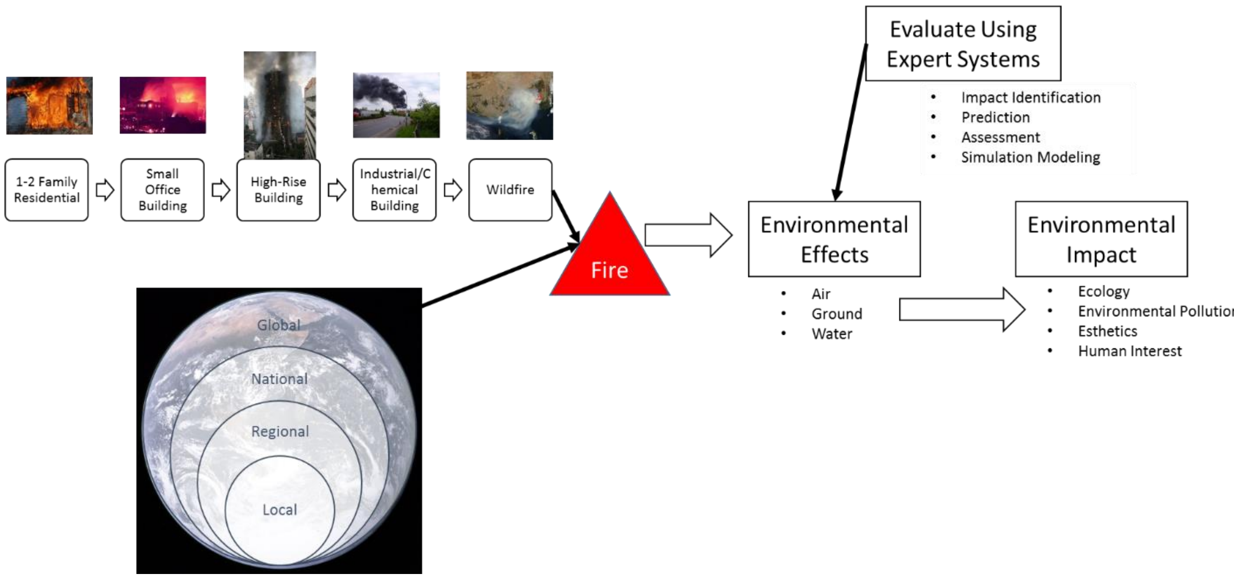

FIGURE 1: CONCEPT FOR AGGREGATING THE ENVIRONMENTAL IMPACT OF FIRE

2. DEFINITION & METHODOLOGIES

2.1. DEFINITION

Environmental impact assessment (EIA) *can be defined as the systematic identification and evaluation of the potential impacts (effects) of proposed projects, plans, programs, or legislative actions, relative to the physical–chemical, biological, cultural, and socioeconomic components of the environment.* (CRC, 1999)

While the general definition for the environmental impact assessment is defined by the CRC handbook through the National Environmental Policy Act (NEPA) of 1969. A working definition for the environmental impact of fire can be defined as:

The systematic identification and evaluation of the potential stressors (hazards), of proposed projects, existing, built and natural, systems and their contents, resulting from an adverse, unwanted fire event, in terms of the physical–chemical, biological, cultural, and socioeconomic components of the environment.

2.2. ENVIRONMENTAL IMPACT ASSESSMENT

There are various environmental impact assessment approaches that have been developed in the United States and worldwide. The Environmental Engineers Handbook presents a range of useful information for conducting an environmental impact assessment (EIA) at various levels of detail, including what issues to consider, how to quantify the effects, and resources to further the depth of the study.

Table 1 shows a matrix that displays the types of methodology used, and the activities that each methodology uses. This table is used throughout the project to guide our research displays the progression of the levels of activity used when conducting an EIA.

The level of detail of the EIA depends on the focus of the EIA, the available data and resources, and the scope of the decision to be made based on the EIA. This is reflected in Table 1 from the Environmental Engineers Handbook.

For this particular effort, we followed the 'expert systems' level of analysis. This meant that expert judgment was applied in the review of materials produced by others on the magnitude of the fire problem, production of environmentally unfriendly products of combustion, impact of those products on the environment, etc., without actually undertaking actual assessments of environmental impact.

2.3. SELECTED METHODOLGY

Fires are adverse events and have been clearly shown as having negative impacts on human life and property, for this study the adverse environmental impacts of unwanted fires are also identified. To accomplish this goal a methodology accepted in the field of environmental engineering was adapted for our purpose. The expert systems approach, described in the CRC Environmental Engineer's Handbook as a way to describe the environmental impact of fire, was selected. (CRC, 1999)

Figure 2 shows the action items that are defined as part of the expert systems approach. Taking advantage of this organizational structure of the actions, the report has been modeled in this sequence.

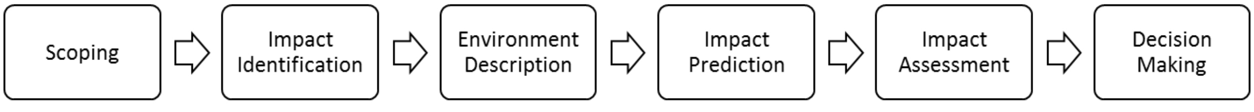

FIGURE 2: PROGRESSION OF STEPS CONDUCTED FOR ENVIRONMENTAL IMPACT ASSESSMENT (CRC, 1999)

TABLE 1: SYNOPSIS OF EIA METHODS AND STUDY ACTIVITIES (CRC, 1999)

Types of Methods in EIA	Define Issues (Scoping)	Identify Impacts	Describe Affected Environment	Predict Impacts	Assess Impacts	Make Decision	Communicate Results
Analogs (look-alikes) (case studies)	X	X		X	X		
Checklists (simple, descriptive, questionnaire)		X	X				X
Decision-focused checklists (MCDM; MAUM; DA; scaling, rating, or ranking: weighting)					X	X	X
Expert opinion (professional judgment, Delphi, adaptive environmental assessment, simulation modeling)		X		X	X		
Expert systems (impact identification, prediction, assessment, decision making)	X	X	X	X	X	X	
Laboratory testing and scale models		X		X			
Literature reviews		X		X	X		
Matrices (simple, stepped, scoring)	X	X		X	X	X	X
Monitoring (baseline)			X		X		
Monitoring (field studies of analogs)				X	X		
Networks (impact trees and chains)		X	X	X			
Overlay mapping (GIS)			X	X	X		X
Photographs and photomontages			X	X			X
Qualitative modeling (conceptual)			X	X			
Quantitative modeling (media, ecosystem, visual, archaeological, systems analysis)			X	X			
Risk assessment	X	X	X	X	X		
Scenarios				X		X	
Trend extrapolation			X	X			

3. HISTORICALLY SIGNIFICANT FIRES

Many fires have an impact on the environment because of the relative ease of transmission of harmful chemicals to the nearby environment. Table 2 contains a list of fires with significant impacts on the environment or that represent a fire where there was a particular effort to address the environmental impacts of the fire and firefighter activity. Possibly one of the most critical fires to identify is the fire in the Sandez chemical warehouse in Basle Switzerland. This fire is important to the history of the environmental impact of fire because the result of the fire was to pollute the Rhine River, causing an international incident between Switzerland and the countries downstream of the pollutants. The next significant fire to discuss is the fire at the Sherwin Williams paint factory in Ohio, USA. This fire is interesting because the facility was located very close to an aquifer that 400,000 needed for drinking water. The incident commander made the decision to not apply water to the fire because the effects of the air pollution was much less than the effects of polluting the aquifer.

TABLE 2: LIST OF FIRES IMPORTANT TO THE STUDY OF THE ENVIRONMENTAL IMPACT OF FIRE (ISO, 2011)

Date	Location	Description
1962-Present	Centralia, USA	Coal mine fire that has been continuously burning causing a large majority of the town to evacuate. Currently there are less than 15 residents still in the town. The fire is extremely difficult to reach and extinguish, though many attempts had been made. The environmental impacts of this fire is the air pollution, greenhouse gas emissions, vegetation die-off. (Brnich Jr & Kowalski-Trakofker, 2010) (Nolter & Vice, 2004) (Pennsylvania Department of Environmental Protection, 2013)
February 1982	Yorkshire, UK	Fire at a warehouse in Yorkshire grew very quickly. The fire department was provided with Transport Emergency Cards (TREM) relating to Herbicides and Octylphenol, however the fire grew very quickly. The fire department attacked the fire with water. The runoff caused widespread major pollution of the local water and land. (Health and Safety Executive, 1993) (Nelson, 2000)
November 1986	Basle, Switzerland	Sandez chemical warehouse was a fire that triggered the study of the environmental impacts of fire worldwide. 10 years after the fire, the eels in the Rhine were not consumable. (New Zealand Fire Service, 2001) (McNamee, 2014)
May 1987	Black Dragon Forest Fire	The Black Dragon fire burnt a total of 72,884 square kilometres (28,141 sq mi) of forest along the Amur river, with three million acres (4687.5 square miles) destroyed on the Chinese side. (Salisbury, 1988)
October 1987	Nantes, France	A chemical warehouse storing inorganic fertilizers suffered a major blaze due to self-sustained decomposition of 20 t of N-P-K products, releasing a massive toxic plume that eventually dispersed over the ocean. Some 15 000 people were evacuated as a precaution. Afterwards, an experimental assessment of the plume toxicity confirmed the toxicity of the effluents. (Marlair, Simonson, & Gann, 2004)
June 1987	Ohio, USA	Sherwin Williams paint warehouse stored almost 1.5 million gallons of paint. Significant because warehouse was located over several aquafers. Also notible for the fact that the fire service assessed the risk of the extinguishment vs the risk of polluting the aquifer. (USFA, 1987)
June 1988	Tours, France	Known as the “Protex” fire, this chemical fire spread vigorously due to the close proximity of flammable and toxic products. The plume zone was some 30 km long and 12 km large (fire plume zone) and provoked major pollution of the river Brenne. (Marlair, Simonson, & Gann, 2004)
February 1990 & May 1990	Hagersville, Canada and Saint-Amable, Canada	Two of the numerous large-scale tire waste fires that have taken place in North America. Tire fires last several days to several months, lead to massive air, soil and water pollution, and extreme difficulties in fire-fighting. Evacuation of people is required in some cases, and fresh water sometimes disrupted for long periods. Lessons learned led to the production of useful guidelines in North America and Europe. (Marlair, Simonson, & Gann, 2004)

Date	Location	Description
1991	Kuwait Oil Wells	As a result of the Iraqi invasion of Kuwait, oil wells were systematically damaged through the use of explosives, resulting in uncontrolled gas and oil blowout fires in some 700 wells. The environmental contamination by both oil leakage and fire gases was severe, in relation with the tremendously important and long-lasting releases of pollutants (equivalent to some 7 400 000 bbls/day) that have affected air and soil, according to the NIST evaluation report from 1994. (EPA, 1991)
July 1992	South Bradford, UK	A major pollution of the aquatic environment resulted from the run-off of some 16 000 m^3 of contaminated water used to fight a fire in the plant of a chemical manufacturer: the UK reference in matters of pollution by contaminated water run-off in fresh water streams. The origin was the proximity of storage of incompatible chemicals. (New Zealand Fire Service, 2001) (Health and Safety Executive, 1993)
October 1995	Wilton, UK	Polypropylene warehouse fire on a chemical complex, which raged for 12 h, due to fault in the lighting system. Some of the fire protection features did not operate correctly as a result of the smoke ventilation system prevented the fusible links of the fire doors to close. The incident generated large quantities of smoke, but an on-site risk assessment considered the smoke non-toxic. (Health and Safety Executive(b), 1995)
December 1995	Somerset West, South Africa	Massive fire of a sulfur stockpile used by three different companies in industrial applications. A unique proof that fire toxicity is a lethal threat, even in the open environment. (Marlair, Simonson, & Gann, 2004)
June 2001	Venizel, France	A fire accident in a paper mill containing polychlorinated biphenyl (PCB) transformers. presented considerable difficulties for emergency response management, and required the medical survey over a year of some 100 people (including journalists), liable to have suffered some exposure to dioxins and PAHs. A case study which reveals that, until the phase-out of a banned product is fully effective, the threat remains. An instructive report was produced on the aftermath of the fire and made public by the French authorities. (Marlair, Simonson, & Gann, 2004)
January 2002	Murcia, France	Large release of toxic effluents arising from a warehouse storing inorganic fertilizers (NPK) in a scenario quite similar to that which occurred in Nantes in 1987.
December 2005	Buncefield, UK	A major fire occurring in an oil storage depot which contained 35,000,000 liters of various types of fuel. The fire burned for several days, emitting massive plumes of dense smoke which, due to the prevailing meteorological conditions, were transported and dispersed in the upper atmosphere. The groundwater under and up to 2 km to the North, East and South-East of the site was contaminated with hydrocarbons and fire-fighting foams from the incident. After two years, the extent of the contamination appeared to be confined to within the immediate vicinity of the depot. Approx. 22,000,000 liters of contaminated fire-fighting water has been treated and safely disposed of. (Health and Safety Commission (c), 2006)
February 2009	Black Saturday Bushfires	A series of brushfires in Victoria, Australia, that were Australia's worst ever natural disaster. They were extreme brushfire-weather conditions resulted in 173 deaths and 414 injuries. There were also 450,000 ha burnt.

4. IMPACTS

4.1. FIRE EFFLUENTS

If an environmental event causes an impact to the ecology, generally it will affect a large area and affect the ecology of that area. This is the more likely outcome of a fire event. We can break the impacts into pathways, over which the hazards travel from the source to the target. The pathways are environmental pollution through water pollution, through air pollution, through land pollution or through noise pollution.

(CRC, 1999). Hazards that can be experienced from a fire include general pollutants/indicators, metals, particulates, polycyclic aromatic hydrocarbons (PAHs), chlorinate dioxins and furans, brominated dioxins and furans, polychlorinated biphenyls and polyfluorinated compounds (e.g., see ISO 26367-2, (Turekova & Balog, 2010), (Simonson, et al., 2000), (Simonson, Andersson, Rosell, Emanuelsson, & Stripple, 2001), (Andersson, Simonson, Rosell, Blomqvist, & Stripple, 2003). From this list we can see that there are a wide variety of chemicals and particulates emitted during fires that have been identified as having a negative impact on the environment. It is necessary to identify and understand which of these substances will have an impact on the three major environmental receptors of concern: the atmospheric, water and terrestrial environments. However, quantification of the impact is difficult, as challenges exist in identifying and appropriately sampling these substances during and following a fire. In addition, the exposure time and persistence in the environment can play a role.

4.2. ENVIRONMENTAL IMPACTS

The fire effluents described in the above section may or may not make an impact on the environment depending on the amount of time of exposure, the means of transmission to the environment, and the susceptibility of the receptor.

4.2.1 TIME SCALE

One of the more clearly defined breakdown of the impacts is the issues differentiation between short term and long term, where short term impacts are considered to occur over a few hours or a few days, at most. Long term impacts are impacts beyond immediate, short term impacts.

SHORT TERM

Short-term environmental impacts from exposure to fires, i.e., impacts occurring after the fire over the period of a few minutes to a few days, pertain mostly to the local environment, within the fire plume zone and water run-off zone. The nature of the impact(s), the exposure pathway(s), and the time period for which this condition is expected to exist shall be reported and should at least include the following contaminants: nitrogen oxides (NO_x), sulphur oxides (SO_x), some metals, halogenated acids (HX) and particulates ((Andersson, et al., 2004), (Simonson, et al., 2000), (FM Global, 2010), (Marlair, Simonson, & Gann, 2004), (USDA, 2002)).

LONG TERM

The long term environmental impacts, resulting from hazards from fire will be considered impacts that are not immediately felt or recognized. An example of this might be the impact of erosion after a wildfire because it happens months to years after the fire had been contained. These effects are focused in the location(s) where the fire occurred or a relatively short distance away, but there are exceptions based upon the pathway that the hazards might take. The following hazards have been identified as having some long term impacts: some metals, polycyclic aromatic hydrocarbons (PAH), polychlorinated, dibenzofurans (PCDF) & polychlorinated dibenzodioxins (PCDD), polybrominated dibenzofurans (PBDF) & polybrominated dibenzodioxins (PBDD), polychlorinated biphenyls (PCB) and perfluorinated compounds (PFC) ((FM Global, 2010), (EPA, 2008), (Blomqvist, 2005), (Andersson, et al., 2004), (Simonson, et al., 2000)).

4.2.2 EFFLUENTS TRANSMISSION TO THE ENVIRONMENT

A critical piece of the transmission is the transport medium. The generalization below is intended to provide guidance to non-experts when determining what the major impacts of concern are.

FIRE EFFLUENTS ENDING UP IN THE AIR

The fire plume will take an object and pyrolysis is and then it will travel upward via buoyancy. The research has shown that the emissions of the toxic and exotoxic species are often involved in the plume as are the inorganic gases, volatile organic compounds (VOCs), the Polycyclic Aromatic Hydrocarbons (PAHs), and the dioxins. These species that are lofted by the plume will be fairly light. The main hazard of these gases are the toxicity of the contents and the susceptibility of the receptors. (USDA, 2002) For example Wildfires often will emit particulates that consist of soot and smoke particles. These particles are not toxic or extremely dangerous to healthy populations, but are dangerous to combine with the existence of asthma or old age.

FIRE EFFLUENTS IN THE WATER

The impact of the fire effects on water have already been shown to be disastrous in the case of Basel Switzerland. The problem is that fire is commonly put out with water and other extinguishing agents, however if proper containment and treatment of the run-off is not conducted there is the opportunity for the water to travel and disrupt a proximate natural water way. Many chemicals and possible pollutants are soluble or can be carried by water to a natural source. Many of the fire effluents that have been identified can lead to negative environmental impacts. One of the more non-specific effluents is the fire effluents of any of the products that a building or warehouse has on-site. In addition Polycyclic Aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), hydrocarbons, dioxins, metals, ammonia, and suspended solids. (USDA, 2005)

FIRE EFFLUENTS IN THE TERRESTRIAL ENVIRONMENT

The impact of fire effects on the terrestrial environment is less of a short term hazard, but might have long term exposure concerns. In addition distribution of the effluents to the terrestrial environment can be a primary pathway, as well as a secondary pathway where effluents would be thrown from the plume down to the ground. Again a critical part of the identification of the effluents will be as to whether there are any hazardous materials stored on site as well as any extinguishing agents used. Polycyclic Aromatic hydrocarbons (PAHs), dioxins, furans, metals, and items that present some form of toxicity or exotoxicity. (USDA, 2005)

4.2.3 Quantification of the Effluents

SAMPLING

Sampling can be conducted a variety of ways and the method and level of analysis is very goal oriented. For example, the United States helped Saudi Arabia and Kuwait analyze their needs for sampling for the duration of the Kuwaiti oil fires. In the Kuwait, initial sampling was conducted to detect the concentrations of Sulfur Dioxide or Hydrogen Sulfide as well as the level and size of particulates. After the initial modeling exercise the following steps were conducted to retrieve data from the fire plumes (EPA, 1991).

- Immediate steps would be taken to collect and analyze meteorological observations and forecasts, record visual observations of the smoke plume, and review existing monitoring data. Plume observations via satellite would be obtained daily,
- Supplemented by periodic on-scene aerial transects designed to characterize the overall geometry of the plume.
- A ground-based sampling network of portable equipment would be installed by EPA and others at approximately 15-20 locations to measure particulate matter less than 10 microns in diameter (the particle size most likely to penetrate deeply into the lungs).

- Measurements of carbon monoxide, carbon dioxide, methane, hydrogen sulfide, sulfur dioxide, particle size distribution, elemental and organic carbon, metals, polycyclic aromatic hydrocarbons and acid aerosols would be obtained close to the fires by NASA and NIST. These measurements should attempt to characterize and categorize emissions from several specific wells.
- Specially equipped aircraft would be deployed to measure downwind plume composition and dispersion, radiative properties and climatic effects, and effects on clouds and precipitation. On the basis of the initial aircraft results, a longer-term sampling program would be designed to monitor the relaxation of the atmospheric environment as the fires are extinguished.

The Kuwait Oil fires was a large scale, long duration environmental event. This gave the EPA time to coordinate and position the wide range of sampling methods. Figure 3 displays a visual of the expanding complexity and expanding timeline of events during an event.

Initially visual observations must be made using observational skills or with a satellite depending on the size and location of the event. An initiating event comes with a high degree of randomness and unpredictability and as a result the most time-efficient methods of sampling should be applied. The next step in the data collection timeline is the use of meteorological information to predict possible effects of weather in the dispersion of any environmental impacts. This should include visual cues, satellite imagery and predictive models. Knowledge of the wind direction as well any precipitation would be useful to determine the fire effects would move and travel. The last step and the most complex step in the sampling process is setting up devices to collect data on different fire effluents that can be used to track concentration and toxicity. This step is highly dependent on the goals and objectives of the entity doing the sampling.

For example if this timeline is going to be used by a fire department responding to a residential structure fire they will first visually observe the event. As a secondary step they will take into account the wind or precipitation, but they most likely will not set up any sampling.

Alternatively if a forest fire is in its incipient stage of growth, satellite imagery is used to pinpoint a location for visual confirmation. The meteorological model is then incorporated into the satellite imagery to create a predictive fire growth model.

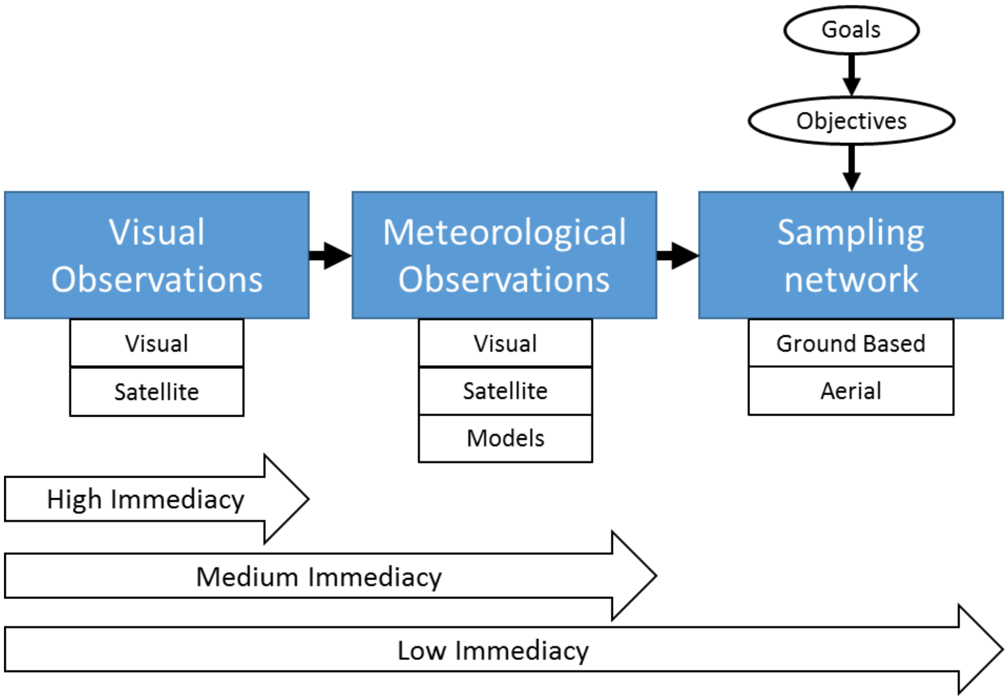

FIGURE 3: FIGURE DESCRIBING THE EXPANDING COMPLEXITY OF DATA COLLECTION DURING AN EVENT.

CALCULATIONS

To calculate the effects of fire, the fire protection industry has many equations and models that are used for fire dynamics applications. For example during the Kuwait oil fires NIST sent a team to the region and they were able to correlate the heat release rate of the crude oil wells to the flame height (Evans, Madrzykowski, & Haynes, 1994). Similarly the EPA has techniques it uses to gauge the environmental effects of certain events. Teams used planes to take air samples to determine how widespread the damage was. Regional temperatures were collected to determine the effect on temperatures that the reduced sunlight had on the region. Air monitoring stations were setup in the major cities in the area to measure the amount of pollution in the air, particularly measuring PM-10, SO_2, and NO_2. This sampling effort combined with the statistical calculation techniques used, led to the conclusion that there the problem was limited to a small area around the oil wells.

To calculate the impacts of fire there have been few studies that quantify the impacts of fire over a wide area and/or aver a lengthier period of time. Blomqvist (2005) performed an estimate of the total amounts of PCDD/F, PAH, and VOC that were emitted from all fires in Sweden during 1999. This was done by estimating the amounts of materials involved in the building fires and fires in specific objects. These then were assigned emission factors for the materials and the objects. This study showed that there is a wide range of results because of the variability involved. The results shows that for PDDD/F garbage fires yield extremely high emissions of PCDD/F, with between 210-870 mg TEQ being emitted. For PAH and VOC dwellings contained the highest emissions, most likely because of the much higher number of fires. These were measured to be 4.8 tons of PAH and 65 tons of VOC emitted from dwelling structures to the atmosphere.

To understand this data a comparison is helpful. In terms of the emission from dioxins (PDFF/F) the emissions from fires are a significant source and are about equivalent to the emissions from traffic and municipal waste combustion.

ON SITE CO_2 RELEASE DATA

The United States Department of Energy (US DOE) has developed data that allows calculation of the embodied energy of different building assemblies (DOE, 2011). The utility of this data will provide information for what the embodied energy and the CO_2 equivalent. The availability of this data provides fire departments and other pertinent parties with the information to calculate the amount of CO_2 that is release based upon the square footage of materials burned. A recommendation is to explore the use of data revealing the embodied CO_2 and how it relates to buildings and building contents. That connection should then be used in conjunction with fire statistics to estimate the approximate CO_2 released from fire. This effort proved to be out of the scope of this work and need to be further analyzed to ensure that there is a scientifically justifiable method for this estimation. One of the challenges is that there is little data to verify any estimate that could be made, however laudable efforts by work at FM (FM Global, 2010) and Lund (Andersson, Simonson, Rosell, Blomqvist, & Stripple, 2003) (Andersson, et al., 2004) (Simonson, Andersson, Rosell, Emanuelsson, & Stripple, 2001) (Simonson, et al., 2000) provide some experimental fire testing results.

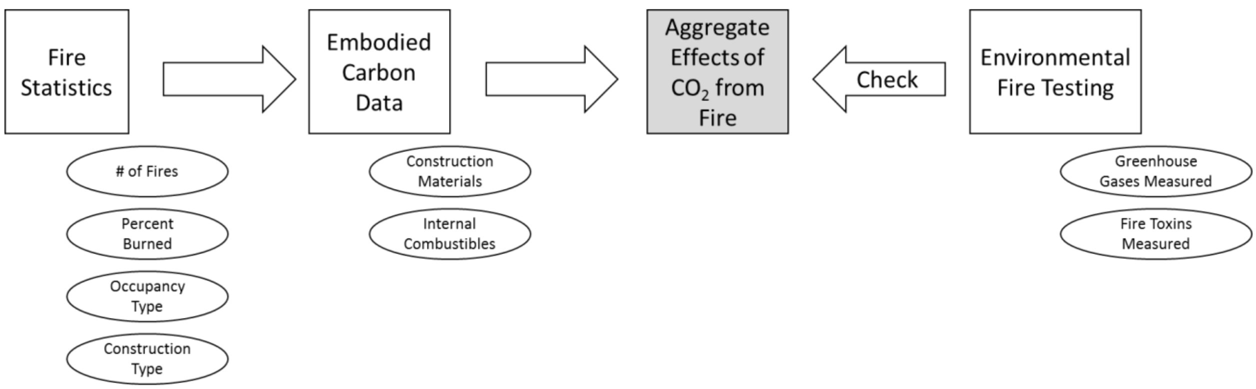

FIGURE 4: GENERAL THEORY TO FIND THE AGGREGATE EFFECTS OF CO_2 WITH LIMITED INPUTS

Figure 4 shows the general connections between the different data sets needed to develop hypothesis on the amount of CO_2 resulting from fires. The first step is to collect the fire statistics for the region you are looking to analyze, whether this be a state, country, or the globe. Specifically the number of fires that have occurred, the percent of the building each fire has burned, the occupancy type, and the construction type would be the minimum amount of data that could be used for an estimate.

These data points are helpful to determine two things about the fires statistics which is the total area burned and what materials were burned. Once those items are determined then the embodied carbon data can be used to find the total embodied carbon which was destroyed by the fire. To check the results it should be compared to the actual testing that was mentioned above.

Impact Prediction

There are numerous methods used to predict the impact on the environment of both project based studies and non-project based studies. A study done by the Water Resources Council in 1983 developed several approaches which can be used to prediction of the impacts (CRC, 1999):

a) Adoption of forecasts made by other agencies or groups
b) Use of scenarios based on differing assumptions regarding resources and plans
c) Use of expert group judgment via the conduction of formalized Delphi studies or the use of the nominal group process
d) Extrapolation approaches based upon the use of trend analysis and simple models of environmental components
e) Analogy and comparative analyses which involve the use of look-alike resources and projects and the application of information from such look-alike conditions to the planning effort.

From the approaches given, there are several which are directly related to prediction of a specific fire event.

4.3. FORECASTS

Forecasts are most relevant for fire for wildland fire events. Wildland fire events can be reasonably predicted by groups such as the United States Forest Service (Wildland Fire Assessment System, 2010). Different models have been developed to use remote sensing, lighting sensing, and in-situ observations to forecast the locations where burning will be more likely.

WILDFIRE MODELING

Once such tool that has been developed can explore hypothetical and real-life wildland fire scenarios to output quantified data of the predicted impacts. There has been extensive research and innovation in the field of modeling and remote sensing. As the cost of computational power goes down as well as the cost of remote optics it is becoming easier to get a special defined picture of wildland fires. With the inputs that are listed below the outputs listed can be found, solely as a modeling exercise. This calculation buildings on the research that the United States Department of Agriculture (USDA) and the USFS has done to characterize and quantify the types of forest and vegetation to aid in their predictive capabilities for where and how severe a wildfire will be (Clinton, Gong, & Scott, 2006) .

Inputs

- Geographic Information System (GIS) data
- Vegetation Data
  - Fuel Model Data
  - Duff
  - Litter
  - Herbs
  - Shrubs
  - Tree Regeneration
  - Live Branch-Wood
  - Live Foliage
- Weather Condition Data
- Fire Perimeters

Outputs (pounds)

- 10 µm Particulates
- 2.5 µm Particulates
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Methane (CH_4)
- Non-Methane Hydrocarbons
- Ammonia (NH_4)
- Nitrous Oxide (N_2O)
- Oxides of Nitrogen (NO_x)
- Sulfur Dioxide (SO_2)

While the inputs to this predictive model may look rather complex and difficult to acquired, it is less difficult then would be thought. Geographic Information System data (GIS) is a technology that is used to capture, manipulate, analyze, and manage all types of special data. (CEGIS, 2014). The vegetation data has been implemented into a series of growth models and will act to predict the types of special vegetation. (USFS, 2013). Weather and climatic data is also provided through the National Oceanic and Atmospheric Administration and they specifically have a focus on the effects of weather on fire (Bussum, 2013). Finally, the use of remote sensing has allowed for stakeholders to have more information about the fire and its movements using multiple different sensing technologies increases the accuracy of the model (USFS, 2015)

4.3.1 Locality-Dependent Impacts

The affected locality of the environmental impact of a fire, or an aggregation of multiple fires should both be identified as part of determining the impacts of fire (see Figure 5). Individual buildings provide the information necessary to look at the environmental effects of the fire. Those affects, can then be aggregated to provide the aggregated environmental effects in a region, nation or the world depending on the data available.

The fire problem in the United States, for example, includes 1,240,000 fires resulting in 3,240 civilian fire fatalities and an estimated $11.5 billion in property loss (Karter, 2014). Data from sources as the US Census, National Association of Home Builders (NAHB) and Commercial Building Energy Consumption Survey (CBECS) can be used to estimate numbers of buildings of different types. We can then look to data to estimate types of construction material and contents (rather generally). This is an example of how, in the United States, data collected / available on the number and types of fires presents the possibility for developing an ‘order of magnitude’ approach to the aggregate environmental impact of fire. Data of a similar volume and sophistication was not easily discovered for the remainder of the world.

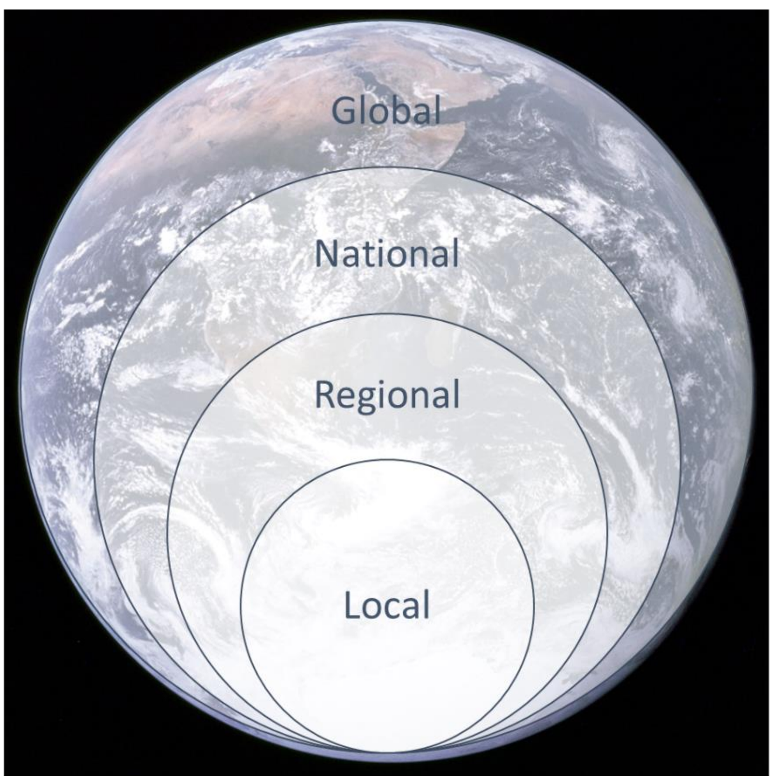

Figure 5: The aggregate effects of fire effects the population and the environment at every locality

Prediction of the impacts based upon the relative size of the fire as well as the locations is described in our taxonomy two ways. First, there are examples that clearly demonstrate that a single fire event creates an impact on the local environment, the regional environment, the national environment, and the international environment. An example to demonstrate this principle, is the Sandoz Chemical Warehouse fire in 1986. The fire represents a single event that had an impact across every definition of locality, as a result of hazardous runoff being distributed via the Rhine River. (Holemann, 1994)

More information was expected to be discovered regarding fire statistics around the globe, however there are a number of countries that provide this information on their websites (see Appendix A: Global Review of Environmental Impact Assessment Legislation). Much of the focus of this study looked the data from the NFPA reports as they provide reliable statistics and they are very accessible to anyone.

Further exploration will be necessary to determine the specific effects at a local, regional, national, and international level. Despite this there were some sources of information that proved useful for global data. The links below are provided in the full bibliography. Further study of the global fire problem is necessary to conduct any aggregation estimates at a global scale.

Lloyds Insurance Group: http://www.lloyds.com/

Geneva Association: https://www.genevaassociation.org/

4.3.2 Building-Dependent Impacts

The extent to which the building involved in a fire event will have an impact on the environmental will be determined by the availability of flammable items, the hazard of the toxins and the risk of a fire event occurring. For example a single residential fire results in different effects than a single industrial plant fire or a single wildfire.

The information for each building is both specific and non-specific, meaning that each building has a defined maximum amount of hazardous materials allowed to limit the hazard to occupants, first responders, and the environment. It is difficult to identify exactly what the building will contain because the contents of each building are unique, however estimates based on previous research and fire statistics are used to find an order-or-magnitude approximation. However it is challenging to bound this problem for industrial and high-hazard structures, which may contain a large array of different chemicals and toxins.

One way to bound the problem is through the definitions of each occupancy, the construction type and the limits of materials allowed in the Building and Fire Codes (ICC(a), 2012) (ICC(b), 2012) (NFPA, 2012). From the ICC Fire Code and the NFPA Fire Code there are limits to the amount of combustible, explosive and flammable materials. In addition it also limits the maximum amount of hazardous material allowed. This acts to limit the amount of hazardous materials, but also alerts the fire department to any increase beyond what they would typically see. This allows the first responders to be cognizant of the hazard and pre-plan ways to mitigate the hazardous condition.

FIRE STATISTICS IN THE US

The fire problem in the United States is reported on by the NFPA. Between the years of 2007-2011 there were approximately 498,500 fires per year (NFPA, 2013). These statistics are important as we look to characterize the environmental impact of fire because of the way they should be used. To use the statistics from the United States, and from other countries, we must be cognizant of the fact that just accounting for the number of fires will give an over estimation of the impacts, whereas accounting for the property damage will more closely equate to the impacts to the environment.

The fire problem as it relates to the environment can be largely identified by the direct property damage information. We assume that the more property damage there is, the higher the effluents to the environment as well as higher the embodied carbon amount that is release from the structures. For example FM Global (FM Global, 2010) did a study to compare the environmental impacts of non-sprinklered residential buildings versus sprinklered residential buildings. One of the criteria that was used was the measured amount of greenhouse gases that were produced. This is one good source that could be used to estimate the greenhouse gases that would be found in a typical residential fire.

RESIDENTIAL

It is estimated that an average of 366,600 home structure fires occurred per year during 2007-2011, causing $7.2 billion in direct property damage per year. (Ahrens, 2013) Of those, the highest number of fire events were in one-to-two family residential occupancies with 52% of all fire events. The most civilian deaths also occurred in one-to-two family residential occupancies fires, accounting for 2,165 deaths or 77% of the civilian deaths. The cost of the direct property damage in the United States was $6.0 billion, with 56% of the damage having occurred in one-to-two family residential occupancies. (NFPA, 2013)

The department of energy reports that between 2005 and 2010 the total building stock went from 108.8 million households to 114.2 million households. (DOE, 2011) Therefore, it is estimated that about 0.32% of the building stock will have a fire in it every year.

LOW-RISE BUSINESS/HIGH-RISE

Buildings occupied by business are typically found in low rise offices up through super-tall buildings. The contents of the business occupancies will generally be the same, with the difference mainly in the total size of the building as well as the construction types, in some cases.

In high-rise buildings, between 2007 through 2011, there were over 46 civilian deaths and 530 injuries. The approximate direct property damage was estimated to be $219 million. High rises are defined as buildings with their highest occupied floor as being 75 feet above the lowest level of fire department access (ICC(a), 2012). The most common occupancies for a high-rise building is for apartment buildings, hotels, office buildings, and facilities that care for the sick. The level of protection in a high-rise building is usually greater because of the additional fire safety measures required by the code. (Hall, 2013)

INDUSTRIAL

About 42,800 fires in industrial and manufacturing properties were reported during 2006 – 2010 in the U.S. fire departments per year. Of those, 30200 were unclassified fires, 4100 were vehicle fires, and these events caused $951 million in property damage per year. (Evarts, 2012)

WILDFIRE

The NFPA tracks structure fires, has compiled the following list of wildland fires that have occur in the United States. As we can see in the 20 years the cost of the largest wildfires in the United States has grown tremendously. (NFPA, 2013) The cost of combating wildfire in the 2014 was $1.5 billion dollars. (National Interagency Fire Center, 2014)

The national interagency fire center (NIFC) is an organization who serves as a coordinator for wildland fire events throughout the United States. NIFC is responsible supporting incidents around the country at all levels of risk and as such it can leverage its own, and its partner organizations, advanced ability to track and respond to wildland fire events. This agency develops the teams that are necessary to respond to a wildland fires and sets up mobile response units. Over the past 10 years the average number of wildfires in the United States per year is 6,964 fires, with an average of 183,481 acres burned every year. The most severe year in the last 10 years was in 2006 when 543,465 acres burned (NIFC, 2014).

TABLE 3: LARGE LOSS WILDLAND FIRES IN THE UNITED STATES BY DOLLAR AMOUNT (NFPA, 2013)

Fire	Loss in Year Fire Occurred	Adjusted Loss in 2012 Dollars
1. Oakland Fire Storm (wildland/urban interface) Oakland, California Oct-91	$1.5 billion	$2.5 billion
2. The Southern California Firestorm* San Diego County, California Oct-07	$1.8 billion	$2.0 billion
3. "Cerro Grande" Wildland Fire (wildland/urban interface) Los Alamos, New Mexico May-00	$1.0 billion	$1.3 billion
4. "Cedar" Wildland Fire Julian, California Oct-03	$1.1 billion	$1.3 billion
5. "Old" Wildland Fire San Bernardino, California Oct-03	$975 million	$1.2 billion
6. Southern California Wildfires of November* Sacramento, CA Nov-08	$800 million	$853 million
7. "Laguna Beach Fire" (wildland/urban interface) Orange County, California Oct-93	$528 million	$838 million
8. Wildland Fire* Florida May–June, 1998	$395 million	$555 million
9. Forest Fire Cloquet, Minnesota Oct-18	$35 million	$532 million
10. "Paint Fire" Goletta Wildland/Urban Interface Santa Barbara, California Jun-90	$237 million	$416 million

*Includes multiple fires.

5. IMPACT ANALYSIS

Impact analysis is the step in the process where different analyses are conducted to determine what the severity of the impacts will be and how they might manifest themselves. Three types of analysis are presented as the most common methods for understanding the impacts. When conducting any type of analysis like this there is a specificity and data problem, meaning that, to fully conduct the analysis requires a significant amount of information about the focus of the analysis.

Table 4 represents generalized analysis inputs and outputs. Ranging from simple and course to sophisticated and refined. The difference between the different types of analysis will be cost, where cost is determined based on both economic costs and time costs. The usage of different analysis changes based upon what is required from the analysis. For example for an incident commander on a fire, the simple and course method will be chosen because of the immediacy of the situation and the low amount of resolution needed. A full life cycle analysis would be a sophisticated and refined study and therefore it is a very costly study both in terms of time and information needed.

TABLE 4: SIMPLE COST BENEFIT SQUARE FOR UNDERSTANDING ENVIRONMENTAL IMPACTS.

	Output	
Input Data	**Coarse**	**Refined**
Simple	Minimize Cost	Minimize Time
Sophisticated	Minimize Expense	High Cost

5.1. LIFE CYCLE ANALYSIS

The life cycle analysis (LCA) is a method that maps the lifecycle of a product, identifies the stages of production, use, and end-of-life processes. The life cycle analysis (LCA) is a powerful tool to show the environmental costs of the lifecycle of a product, process, or policy. This tool is most commonly used in to look at individual products and processes, however recent interest by different industry sectors, has led to the creation of tools to study a building as a whole.

In addition, the fire community developed their own version of an LCA, called the Fire-LCA. The methodology was developed specifically to identify the stages in the products lifecycle where a fire will occur. (Simonson, Andersson, & Blomqvist, Environmental Assessment of Fires in Products Using the Fire-LCA Model, 2005). The Fire-LCA process is primarily the same process as the typical LCA process with the difference being that it includes modules to account for accidents, like fires. It also includes modules that recognize the extent of the damaged area, the fire extinguishment and the replacement of damaged materials. The methodology was developed at SP in Sweeden (Simonson, et al., 2000) especially by Simonson, Blomqvist, Andersson. The effort resulted in a comprehensive guidance framework for conducting a Fire-LCA (Andersson, et al., 2004) as well as several full case studies (Simonson, et al., 2000), (Simonson, Andersson, Rosell, Emanuelsson, & Stripple, 2001), (Andersson, Simonson, Rosell, Blomqvist, & Stripple, 2003).

The relative effort that is required for the life cycle analysis is significant. For example, Hamzi, 2008, displays the steps to conduct a life cycle analysis on storage tanks used in crude oil material production. To complete the analysis, statistics on the following are required:

- Type of complex where accidents occurred
- Type of tank contents
- Type of accident {fire, explosion, spill, etc.}
- Cause of Tank Accidents {lightening, maintenance, failure, etc.}
- Size of tank
- Fire emissions

To adapt the methods of Hamzi et al (2008) to an analysis of a building, Figure 6, was developed to show one example of how the life cycle analysis of a building could be adapted to fit into the Fire-LCA method. Conducting this type of analysis, especially in the United States, is made simpler by the fact that there are several tools used to calculate the life cycle costs of materials and practices, however this is still a very complicated and involved process.

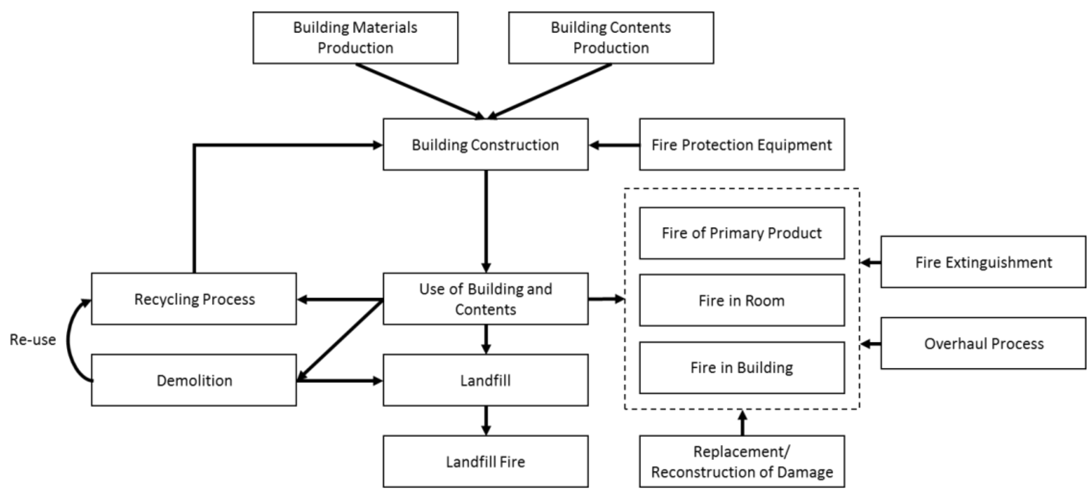

FIGURE 6: METHOD FOR ADAPTING THE FIRE-LCA MODEL TO BUILDINGS (ADAPTED FROM (HAMZI, LONDICHE, & BOURMADA, 2008))

5.1.1 CALCULATION TOOLS

The interest in sustainability in recent years, has led to several tools being available with which to calculate the various values important to the environment. The two tools listed below are for informational purposes only, and do not indicate a particular endorsement to any product or tool.

These tools are comprehensive and represent viable ways to produce easy result with little user input. These tools are built to include massive libraries containing information to the various outputs. For example they have data regarding the embodied CO_2 for the most common building components for the totality of the building.

ATHENA IMPACT ESTIMATOR

The Athena Impact Estimator is a spreadsheet tool that is used to quantify the life cycle analysis of a residential building. This is a free tool that is available to the public. The tool was built in part to comply with LEED V4, the International Green Construction Guide (IgCC), the California Green Building Standards Code, ASTM E2921 – 2013, and EN 15978. The tool is very easy to use for almost anyone and breaks down the process of conducting an LCA by dividing each part of the house into its own section. The data input by the user is typically the materials that are being used and then the number and size of those materials. In this way it can also help show if there are certain materials or sizes that could be altered to create a better lifecycle impact for the building. A similar approach that identifies possibly fire issues would be extremely helpful and powerful. (Bowick, O'Connor, & Meil, 2014) http://calculatelca.com/software/impact-estimator/

SITEWISE™

SiteWise™ is a stand-alone tool developed jointly by the U.S. Navy, the U.S. Army, the U.S. Army Corps of Engineers (USACE), and Battelle that assesses the remedy footprint of a remedial alternative/technology. This tool includes six main metrics in it calculation (Bhargava & Sirabian, 2011):

(1) greenhouse gas (GHG) emissions;
(2) energy use (total energy use and electricity from renewable and non-renewable sources);
(3) air emissions of criteria pollutants (total emissions and onsite emissions) including nitrogen (NO_x), sulfur oxide (SO_x), and particulate matter (PM);
(4) water consumption;
(5) resource consumption (landfill space and top soil consumption); and
(6) worker safety (risk of fatality, injury and lost hours).

This model breaks down the process or activity into blocks over which it can properly identify the above metrics. In this way it will assign every part of the issue a metric and then sums them together. By approaching this analysis in this way the tool attempts to remove the double counting of environmental factors.

The inputs that need to be considered include (Bhargava & Sirabian, 2011):

(1) production of material required by the activity;
(2) transportation of the required materials, equipment and personnel to and from the site;
(3) all on-site activities to be performed (e.g., equipment operation); and
(4) management of the waste produced by the activity.

BEES

Building for Environmental and Economic Sustainability (BEES), is a tool that gauges the environmental performance of building products using a life cycle analysis (LCA) as specified in the ISO 14040 series of standards (Lippiatt, Greig, & Lavappa, 2010). BEES was developed by NIST's Applied Economics Office. This tool incorporates all stages in the life of a product from the raw material acquisition to the recycling or waste management of the product. In addition the economic performance is determined by finding the costs from the initial investment to the cost of repair and disposal. This is done by using the standard ASTM Life-Cycle cost method (ASTM E917, 2013).

This is a tool that is would be useful during the construction of building to use as a decision tool. Additionally this tool can be used after an incident to determine what the product's environmental impact would be. http://www.nist.gov/el/economics/BEESSoftware.cfm

5.1.2 Regulatory Frameworks

The American standard ASTM E29212 provides minimum requirements when conducting whole-building LCA for the purpose of attaining building rating system and code compliance. The European EN 159783 is an LCA standard that is increasingly becoming the common method for describing the system boundary of whole-building LCA. (Bowick, O'Connor, & Meil, 2014) The ISO standards group TC 207 SC 5 is responsible for Life Cycle Assessment Standards falling under Environmental Management. The fact that LCA has received its own standards committee represents the importance that this tool is seen to have by the regulatory committee. (ISO, 2014)

Regulatory Frameworks:

- ASTM E2921: Standard Practice for Minimum Criteria for Comparing Whole Building Life Cycle Assessments for Use with Building Codes and Rating Systems1
- EN 15978: Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method
- ISO 14040: Environmental management -- Life cycle assessment -- Principles and framework
- ISO 14044: Environmental management -- Life cycle assessment -- Requirements and guidelines
- ISO 14045: Environmental management -- Eco-efficiency assessment of product systems -- Principles, requirements and guidelines
- ISO 14047: Environmental management -- Life cycle assessment -- Illustrative examples on how to apply ISO 14044 to impact assessment situations
- ISO 14071: Environmental management -- Life cycle assessment -- Critical review processes and reviewer competencies

This is only a piece of the global push for better informed environmental policy. The inclusion of quantified analysis tools in regulatory frameworks and legislation is a positive step forward to fully understanding the environmental impact of the choices that are made at the highest levels. Further discussion of the regulatory environment is presented in Appendix A: Global Review of Environmental Impact Assessment Legislation.

5.2. COST-BENEFIT ANALYSIS

The cost-benefit analysis (CBA) is another technique that is commonly used to look at products, processes, or legislation to objectively quantify the costs involved and compares them with their benefits. The cost-benefit analysis will not only account for the direct economic costs, but for the costs to the whole process, product, or legislation. Similarly to the life cycle analysis, the cost benefit analysis required quantified data for items that have not traditionally been communicated with quantified data.

The Building Research Establishment (BRE) conducted a cost-benefit analysis to study the effect of sprinkler systems in warehouses. They assumed six building types ranging from small to large warehouses, with or without sprinklers. The analysis considered the “Whole Life Costs” of a building. This took into account such things as the buildings area, to the annual maintenance of the system to the frequency and impact of a fire. The impacts such as the size and impact of the smoke were taken into account as well as the injuries/casualties, and whether the building needed to be demolished. (BRE Global, 2013)

The environmental impact of fire has been done using two metrics one metric is using tons of CO_2 and the other is using ecopoints. Where ecopoints are normalized so that the annual environmental impact of an average person is 100 ecopoints. The data points that are used to make up that metric are as follows:

- Acidification
- Photochemical Ozone Creation
- Eutrophication
- Fossil Fuel Depletion
- Waste Disposal
- Exotoxicity to land
- Nuclear Waste
- Exotoxicity to Freshwater
- Human Toxicity
- Stratospheric Ozone Depletion
- Mineral Resource Extraction
- Water Extraction
- Climate Change

For this study BRE did not look at the life cycle cost of the building. Instead they looked at the environmental impact of a warehouse, with a rack storage system, without a sprinkler system and then at a warehouse, with a rack storage system, with a sprinkler system.

This environmental impact assessment in this case focused on the costs associated with building the building and the sprinkler system and the contents, but not the actual fire incidence. Included in this is the study of solid emission resulting from the fire incident. Additionally, BRE would like sufficient data to complete their "Environmental Profiles Methodology".

The next realization for the environmental impact assessment was to give a comparative estimate between the impacts of a fire in a building with sprinklers versus one without a sprinkler system. Including an estimate of the impact of burning materials, replacing contents, rebuilding, and water usage.

The cost-benefit analyses is useful for studying the environmental impact of fire as a basis for design including the fire protection systems because it presents the information as economic data. The study from BRE looking at whether to include sprinklers is one example, but the cost-benefit analysis could also be used to study any aspect of the fire system design. The boundaries of a cost-benefit study can vary, so it is advised that an official document is used to bound and define the analysis using something like ASTM E917.

5.3. RISK ASSESSMENT

Risk assessment is used across many industries for many uses, for the use of environmental impact it is important that a full risk assessment is conducted to properly understand the impacts. The use of risk assessment techniques will also allow translation to risk management and risk-informed decision making.

There are numerous methods for conducting a risk assessment exercise, which are in part dependent on the level of detail needed and the data that is available. There are three main levels of detail that the risk can be assessed which are through purely qualitative methods, semi-quantitative methods, or purely quantitative methods. A qualitative risk assessment analysis will require the least level of detail and the least data, whereas a quantitative risk assessment analysis will require the highest level of detail and more data. The types of analysis that can be done range from a simple unstructured method to a quantitative risk assessment (QRA) or probabilistic risk analysis (PRA) (Ramachandran & Charters, 2011). Other methods include (Morandini, Maher, & Schene, 1991), (Ramachandran & Charters, 2011):

- HAZAN – Hazard Analysis
- Matrix Methods
- Checklists
- GOFA – Goal Oriented Failure Analysis
- Delphi
- HAZID – Hazard Identification
- HAZOP – Hazard and Operability Study
- Quantative Risk Assessment (QRA)
- Probabilistic Risk Assessment (PRA)
- Consequence Analysis (CA)
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Cause-Consequence Analysis
- Failure Modes, Effects, and Criticality Analysis (FMECA)

The process of risk assessment can be conducted through a variety of methods depending on the problem being studied and the results that are desired. The process of assessing the risk of fire on the environment requires additional study because of the gaps in some of our knowledge as well as the specificity and complexity of the issues involved.

There were two major organizations that were working in this area and provided good guidance on future steps. The first is the Environmental Protection Agency (EPA). The EPA uses the framework shown in

Figure 7 to conduct their ecological risk assessments. The other organization that is influential for looking at the environmental impacts of fire is the United States Department of Agriculture (USDA). The USDA, in conjunction with its child organization the United States Forest Service (USFS), has done a significant amount of work to assess the impacts of wildland fire-fighting chemicals (Modovsky, 2007) and the impacts seen at the Wildland-Urban Interface (WUI) (USDA, 2013).

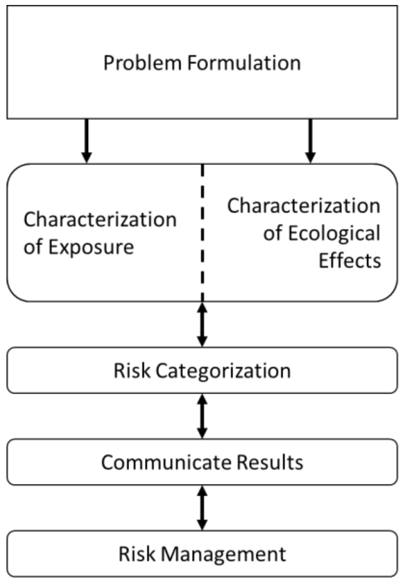

FIGURE 7: EPA RISK ASSESSMENT FRAMEWORK (EPA, 1998)

To perform a fully formed risk assessment a proper framework needs to be identified. Figure 8 represents a piece of the problem for assessing the environmental impacts of fire. First there is the source of the risk, which in this case will be the fire. The source itself is comprised of several hazards of concern ranging from chemical, physical, biological, or nutritional. These make up the hazards in the risk assessment process. The hazards, which are being considered are written up in chapter 4 of this document. Then the pathways, or the ways that the hazards gets from the source to the target. In the case of fire and many other events, the pathways for the impact is through the air, water, and the ground. For the hazard to reach the target it still needs a way to affect the organism or area through either ingestion or contact. Once the hazard reaches the target (receptor) the target must process the hazard, be affected by the toxicity, and then think about the final effects. There are some hazards that are able to be processed, but it is very dependent on the toxicity of the hazard. The toxicity is separated into how it affects the target. The toxicity is either acute, sub-chronic, chronic, or intermittent.

An example of this process is a source fire is being extinguished with water, where the hazard is the chemical runoff, the water then flows to a river by means of the surface water runoff. The targets of fish, crustaceans, and algae all either ingest or contact the chemical runoff. The chemicals are then absorbed and metabolized when the target processes the chemical. The toxicity of the exposed depends of the population, size and potency of the chemicals but ultimately it can cause birth defects or mortality in the species in the river.

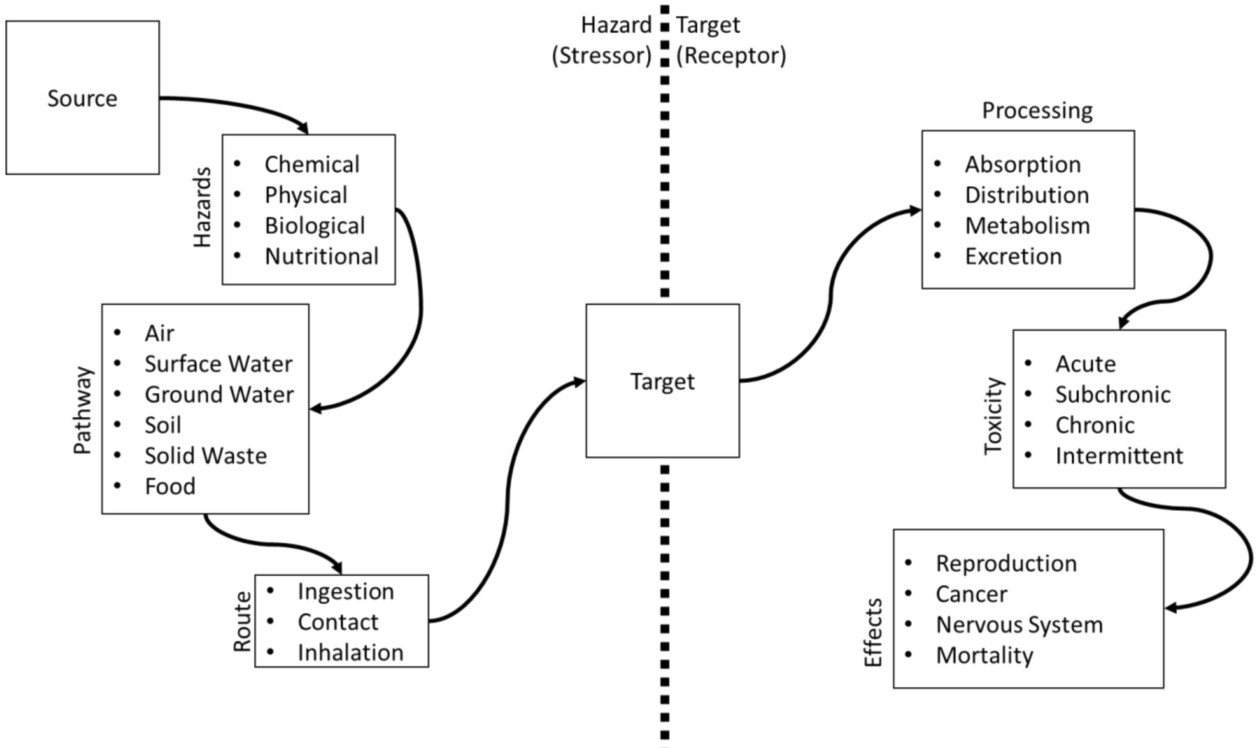

FIGURE 8: PLANNING AN ECOLOGICAL RISK ASSESSMENT (CREATED BASED ON INFORMATION FROM (EPA, 2012))

5.3.1 REGULATORY POLICY

Environmental Policy is typically broken down into the different pathways that the environment is exposed to stressors (hazards). These are:

- Air Quality
- Surface Water Quality
- Ground Water Health
- Soil Health
- Solid Waste Management
- Food Safety

Additionally there is legislation that focuses on the Environmental Impacts itself, which typically requires an environmental impact statement (EIS) to prove that the environmental impact will be limited. This is a better quantification of the

Historically environmental legislation is difficult to implement because it is not only a local issue, but also a regional issue as well as global issue. Global groups like the United Nations greatly assist in unifying the ideas and policies. The following includes a list of regulatory sources for environmental policy. This is included to provide an idea of what the different regions and countries have done to reduce environmental impact and because one possible outcome of this research is additional legislation it was decided to include examples from around the world. This is further explored in Appendix A, where environmental impact policy is discussed.

1. Global Groups
   - United Nations (UN)
     The United Nations provides guidance on their version of an environmental impact assessment through their Economics and Trade Branch that is under the Environment program.
     http://www.unep.ch/etb/publications/enviImpAsse.php
   - International Standards Organization (ISO)
     - ISO 16732-1:2012 Fire safety engineering - Fire risk assessment - Part 1: General
     - ISO/TR 16732-2:2012 Fire Safety Engineering - Fire risk assessment - Part 2: Example of an office building
     - ISO/TR 16732-3:2013 Fire safety engineering - Fire risk assessment - Part 3: Example of an industrial property
2. Regional Groups
   - Asia
     The Asian Environmental Compliance and Enforcement Network (AECEN) is a collaborative effort across the countries of Cambodia, China, India, Indonesia, Japan, Korea, Laos, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam. This regional group works to improve collaboration across the region.
     http://www.aecen.org/
     http://www.aecen.org/eia-compendium
   - European Union (EU)
     The European Union is a collection of Nations on the European continent. Their legislation was first adopted 25 years ago in 1990
     http://ec.europa.eu/environment/eia/review.htm
3. Individual Countries
   - Australia
     http://www.environment.gov.au/about-us/legislation
   - Canada
     https://www.ceaa-acee.gc.ca/
   - China
     http://www.npc.gov.cn/englishnpc/Law/2007-12/06/content_1382122.htm
   - Egypt
     http://www.eeaa.gov.eg/English/main/eia.asp
   - Hong Kong
     http://www.epd.gov.hk/eia/english/register/aeiara/all.html
   - India
     http://envfor.nic.in/division/introduction-8
   - Ireland
     http://www.epa.ie/monitoringassessment/assessment/eia/#.VMssXv54pcQ
   - Malaysia
     http://www.doe.gov.my/eia/wp-content/uploads/2013/06/EIA-Procedure-and-Requirements-in-Malaysia.pdf
   - New Zealand
     http://www.nzaia.org.nz/
   - Sri Lanka
     http://www.cea.lk/web/index.php/en/environmental-impact-assessment-eia-procedure-in-sri-lanka
   - United States
     http://www.epa.gov/reg3esd1/nepa/eis.htm

6. DECISION MAKING

Evaluating the environmental impact of fire would benefit on the design side by including in a decision making process. The analysis tools mentioned above all are useful to look at a product, process, or new legislation aimed at promoting or incorporating environmental impact assessments. Although decision tools available for understanding the environmental impacts of fire are not well known, there are several steps that could be taken to improve access to useful tools, methodologies and frameworks. The tools for analyzing the environmental impact mentioned above can help in making specific choice over another depending on what the stakeholders state is most important.

6.1. METHODS FOR QUANTIFICATION

The CRC handbook, from which the methodology used in this report was taken, compiles several decision making tools, as summarized below.

6.1.1 MATRICES

Table 5: Interaction matrix between environmental factors and effects of the fire Table 6 is an example of a matrix technique that can be used to rate the criteria in terms of the impact. This is a powerful tool to break down the environmental effects and the sources of those effects by conducting qualitative or quantitative analysis.

TABLE 5: INTERACTION MATRIX BETWEEN ENVIRONMENTAL FACTORS AND EFFECTS OF THE FIRE (CRC, 1999)

Environmental Factor/ Resource	Existing Quality	Fire Phase			
		Fire Plume Effluents	Fire Department Intervention	Long Term Effects	Resultant Quality
Atmospheric Effects					
Aquatic Effects					
Effects on Plants and Animals					
Subsurface Effects					
Acoustic Effects					

A=Adverse Impact
M=Mitigation measure planned
a=small adverse impact
O=No anticipated impact
NA=Environmental Factor not Applicable

SA=Significant Adverse Impact
b=small beneficial impact
B=Beneficial Impact
SB=Significant Beneficial Impact

For example, a small scale residential fire event can be analyzed as below:

TABLE 6: EXAMPLE OF INTERACTION MATRIX BETWEEN ENVIRONMENTAL FACTORS AND EFFECTS OF THE FIRE

Environmental Factor/ Resource	Existing Quality	Fire Phase			
		Fire Plume Effluents	Fire Department Intervention	Long Term Effects	Resultant Quality
Atmosphere	NA	A	A	O	A
Ground Water	NA	M	M	A	a
Plants and Animals	NA	O		O	a
Subsurface	NA	O	O	O	O
Acoustics	NA	O	O	O	O

From the matrix analysis for this small scale residential fire we are able to qualitatively estimate the impacts based on a scale ranging from adverse to not applicable. The initial assessment considers the atmosphere and then the impact severity classification is given based on the different phases of the fire. The fire plume effluents are those products of combustion that are buoyant and will be carried upwards and dispersed through the air. The fire department intervention describes the impacts that the fire department will cause from attacking the fire. The long term effects column describes what impacts the environment will still be affected by in the months or year after the fire. The resultant quality of the environment is different than the long term effects in that it describes the result of the aftermath of the fire, and gives an idea as to the severity of the effects.

6.1.2 SLCA

The first step towards creating effective decision tools is to customize a tool to a use case. This is seen in the application of LCA, where there are many tools for designers to understand the impact of choosing one material or building method over another.

One example of a Life Cycle Analysis process, that can be used for decision making, is from the United States Department of Defense (ODUSD(I&E), 2013). This example would purport to be useful because it performs an adaptation to the typical LCA process to create the streamlined life cycle assessment (SLCA). This process is pertinent for several reasons, but the clearest is that it is useful as a decision tool to compare the relative magnitude of the impacts between two or more choices. It does this by limiting the number of inputs that the user is responsible for acquiring and inputting into the LCA model. It incorporates simplified processes in the following areas:

- Emission factors
- Qualitative scoring methodologies for water and land impacts

By linking generalized emissions data the result is easier to obtain a comparison between two different data sources. Figure 9 and Figure 10 show the difference in inputs for the LCA and the SLCA, it is clear that the steps have been simplified in the process flow diagram using a couple of different methods. First, one of the most restrictive parts of an LCA is the amount and complexity of the inputs that are required. However in this example the number of inputs is simplified by generalizing the emissions factors, and by using scoring factors to characterize the impacts on the water and land. Using a system of generalized data allows for easier data input with little loss in quality of the results. (ODUSD(I&E), 2013)

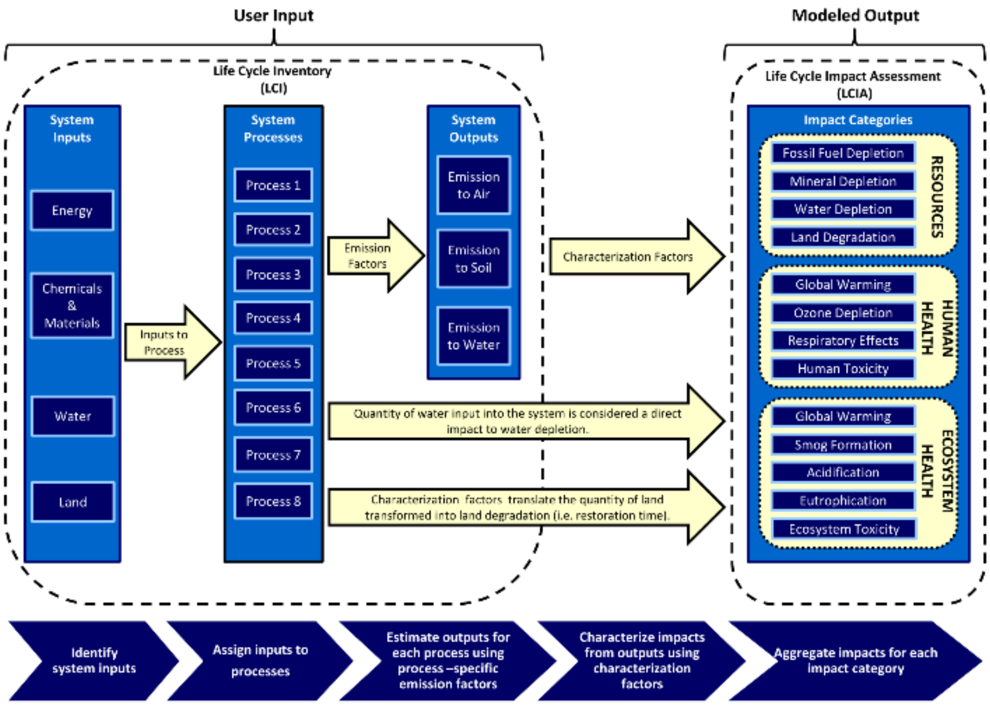

Figure 9: Process Flow Diagram for LCA Methodology (ODUSD(I&E), 2013)

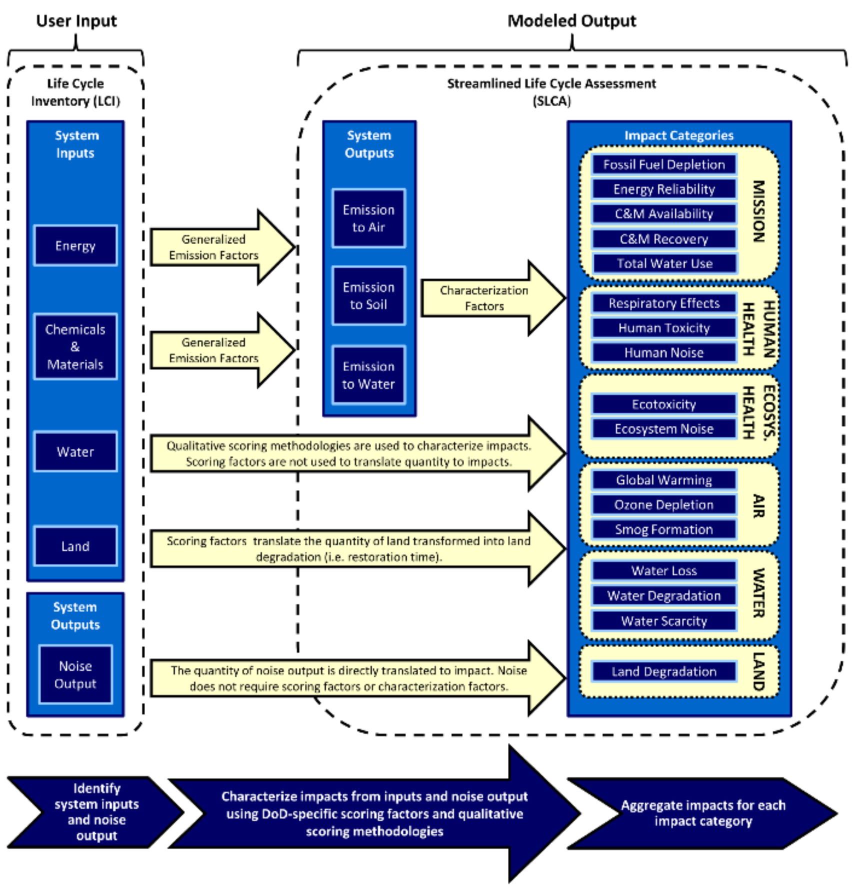

Figure 10: Process Flow Diagram for SLCA Methodology (ODUSD(I&E), 2013)

Figure 11 is a different tool than the matrix approach but the advantage is that it will yield a visual tool, where the larger the area the larger the environmental impact. Additionally a visual of the differences between two options can show how the items in question vary and which choices lead to the least environmental impact. The spider chart is a useful visual because it normalizes the value of the environmental impact for each criterion and clearly displays the footprint of that alternative.

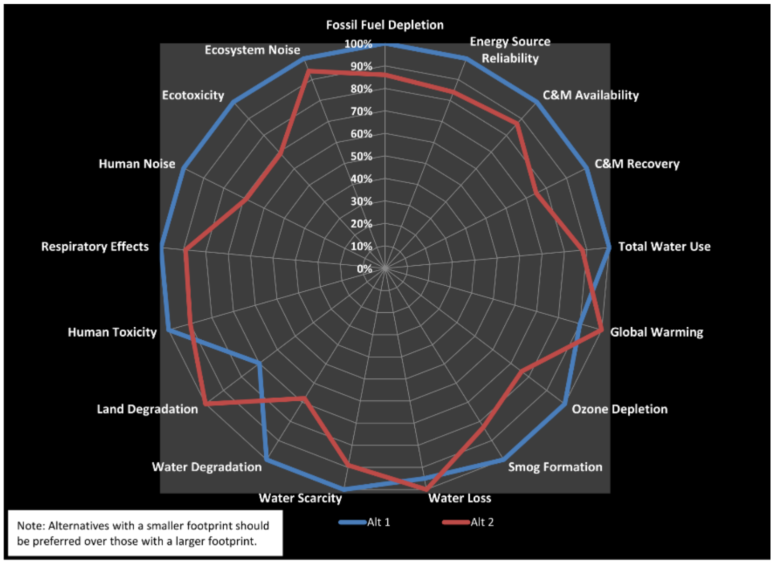

Figure 11: Example Spider Web Chart (ODUSD(I&E), 2013)7.2 Risk Decision Process

A risk characterization is part of a process that begins with the formation of a problem and ends with a decision (Understanding Risk, 1996). The multidimensionality of risk and the many ways it can be viewed help explain why risk characterizations sometimes lack authority for some of the interested and affected parties to a decision, even when the characterizations are supported by high-quality analysis. Problem formulation has practical implications for other steps in the risk decision process. It shapes choices about which options to consider and which possible adverse outcomes to analyze, which are choices that are a critical to the success of risk characterization. A risk characterization must consider the range of plausible decision options to meet the needs of participants in a decision, to avoid being seen as biased and inadequate. Organizations responsible for risk characterizations should make efforts to identify the range of decision options that experts and the spectrum of interested and affected parties consider viable. This process demands familiarity with the context of decision, knowledge about scientific and technical aspects of the possible risks, and sometimes creativity and imagination.

6.1.3 Ecological Effects

One important outcome is harm to nonhuman organisms and ecosystems (Understanding Risk, 1996). An analysis can be challenging as it is difficult to determine the effects on individual animals or plants, local populations of a certain species, an ecosystems, or on the survival of endangered species. Ecological risk analysis requires an understanding of how the affected ecosystem functions. These effects are difficult to measure and still being studied to understand the outcome. Qualitative assessments of ecological risks can provide useful insights for environmental decision making. There is a need to develop appropriate tools for assessing the value of ecological systems, including both economic and noneconomic values.

6.1.4 Effects on Future

Risk decisions on future generations and environment require a different kind of consideration from risk to current situation (Understanding Risk, 1996). As was evidenced by Table 3 the largest wildfires in history have been over the last decade or so. Drought, disease and hotter temperatures are causing wildland fires to be larger than in the past. Small naturally occurring fires, like what was historically seen, were healthy for the environment as it caused a changeover of the nutrients in the area and allows for new life and growth. A large forest fire typically leaves damage on the environment as it burns down trees, produces effluents, and kills lives of plants, insects and animals. The difference is that a small fire will burn at a lower temperature than a large fire. The hotter temperatures cause much more of the soil to be burned causing sterility in the top layer and limits the ability for new growth. The results might not lead to an immediate negative influence, but the releases of toxic materials and physical change of the land could cause harm in the future. A large loss of species could lead to change in an ecosystem, which could lead to a potential damage on the environment. It is difficult to assess the risks to the future generation without considering possible social changes as well as the operation of physical and biological processes over a long term. However, it is an important factor to consider when making decisions.

The trend for larger fires in recent years has caused forest managers to evaluate how they protect their forests. One major hazard is the amount of fuel loading that has accumulated because of the suppression of health fires. Now and in the future it is expected that more thinning and prescribed burns will be conducted to get the forest and its fuel load at a healthy level. Additionally there have been a number of issues of the wildland-urban interface (WUI). Because of this states like Oregon, where homes are commonly in the woods, have to comply with WUI laws. These laws advocate that homeowners clear trees and brush away from their homes.

6.1.5 Risk Measurement

Choosing a risk measure for an event could be complex and judgmental (Understanding Risk, 1996). It is different depending on the focus of an outcome. For example, the list below shows different ways that risks of a fire can be measured:

- Death per million people in the population
- Death per million people within x miles of the source
- Death per unit of concentration
- Death per facility
- Deaths per ton of toxic substance released
- Deaths per million dollars of product produced

The choice of a measure can make a difference in analysis when one risk is compared with another. It is very important to clarify what information is presented from what point of view. An environmentalist might be more interested in the number of deaths per unit of concentration of fire effluents, compared to a policymaker who might be interested in the number of deaths per facility to modify the regulations. One area could be more relevant than the other depending on who is looking at the problem, and it is recommended to avoid choosing misleading measure.

7. GAPS

This research has identified that a significant amount of information is available regarding the environment and the fire effects. However, the information is not complete, nor are the means to utilize that information in decision making. The following gaps have been identified, where additional knowledge and information could be researched in more depth and made available for decision makers.

1. Reporting/Study post fire event

From the beginning of the report several high profile fires with adverse environmental effects were described. For those fires, some information was able to be tracked down, but it was surprising how difficult it was. For most other fires, where concern for the environment was not considered there is little information. A reporting mechanism for fire departments to provide any feedback regarding the risk management of the fire during the event should be explored.

2. Process for EIA during construction

It is becoming common place for buildings to be constructed with some level of certification as to their sustainability, namely LEED in the United States. The building codes are catching up to this level of energy efficiency. It is recommended that an environmental impact assessment (EIA), which includes a fire event, be conducted.

3. Risk assessment tools for fire departments

There are some fire events which did have good environmental risk assessment done by the incident command, however there were also some fire events where better defined risk management techniques would have provided better guidance for the incident commanders. New tools and methods should be explored that provide fire departments with a clearer direction about which intervention technique(s) would be the most beneficial.

4. Exploring the impact of building contents

The contents of a building can change from year to year or even hour to hour depending on the occupancy. The contents of a building can make a difference when choosing a design fire for a space and it is seemingly similar for an environmental impact study. For example a large warehouse filled with bricks would be very different than a warehouse filled with fertilizer, herbicide, and other pesticides both in terms of the fire and that the environmental impacts would result. It is recommended that some sensitivity studies be conducted to determine the effect of contents beyond the studies from FM Global and BRE.

5. Exploring the impact of fire retardants

As building contents change to be more susceptible to fire, new fire retardants are being created to challenge the fire ignition and initial growth. It is recommended that a database of fire retardants and the products of combustion, when they are burned, is created to more fully understand their hazard and toxicity.

6. Detailed fire information for global fire problem

NFPA provides good records for the fire problem in the United States, as do many other countries, but it is difficult to find information regarding fires for the entire world. With the advance of sustainable design and rigid guidelines being developed there should be additional detailed records kept about the fire. The record keeping of fire events in other countries is most likely a political issue as well as a logistical issue, regardless options for expanding fire and environmental impact events should be explored.

8. CONCLUSIONS AND FUTURE WORK

This effort identified, summarized and compiled a large database of resources which help to define issues associated with characterizing the environmental impacts of fire. The outcomes of this effort can provide solid foundation for additional research in this area. The following outlines future research which could be of benefit in this area. Three major areas for future research are suggested, each aimed at providing environmental impact assessment tools for different stakeholder groups:

1. Decision tool for first responders
    i) Quantified information about hazards
    ii) Quantified information about contents
    iii) Quantified information about fire extinguishing materials
    iv) Risk management framework for quick/easy analysis
    v) Methodologies to report environmental impacts of fires
    vi) Survey to determine, whether and to what extent first responders consider environmental impacts of fire
2. Decision tools for designers
    i) Quantified information regarding hazards
    ii) Tool describing differences of the environmental effects of one product undergoing combustion versus another product
    iii) Survey to determine, whether and to what extent designers consider environmental impacts of fire
    iv) Development of a decision tool incorporating quantified analysis techniques {LCA, CBA, RA} to compare the levels of fire protection at the design stage.
3. Decision tool for policy makers
    i) Information regarding aggregate fire problem
    ii) Methods of gathering necessary data from the international community
    iii) Comparative study of existing global regulatory frameworks
    iv) Study to identify paths to incorporating fire in environmental policy
    v) Survey to determine, whether and to what extent policy makers consider environmental impacts of fire
    vi) Development of a decision tool incorporating quantified analysis techniques {LCA, CBA, RA} to compare the levels of fire protection at the building code/policy level.

Prioritization of these efforts will depend on the goals and objectives of the responsible stakeholder groups. If the goal is to improve the environmental impact from first responders and the fire service then number one (1) should be undertaken to understand more fully the environmental impacts that the fire service contributes when attacking a fire and what possible changes they can make to reduce their environmental impact. Similarly fire protection designers can make a number of choices that affect the environmental impact of a building when considering if a fire does occur. There are numerous tools that exist to calculate the environmental footprint of a building and similar techniques could be used to account for the effects of fire. Number two (2) would involve exploring ways to incorporate the comparable sustainability between different types of fire protection measures. This could help answer questions as to what extent should sprinklers be implemented versus structural fire protection. The decision tool for policy makers described in number three (3) could be developed to understand the fire problem from a holistic viewpoint including the use of fire protection (preventive) and fire intervention (attack). To accomplish this an agreed way to calculate the aggregate effects of the fire would need to be established. A large concern with doing this currently is the lack of equivalent data from country to country. Another concern that needs to be addressed is which impacts are considered important and how to rank impacts that effect different parts of the environment, for different periods of time. If these can be resolved it is recommended that we determine an aggregate data set for comparison to other sources of environmental impacts as well as to get an accurate picture of the problem. Then ways to better incorporate prevention and intervention techniques could be implemented from a policy point of view. The regulation that is being written to save homes and buildings from wildfires by implementing WUI policies in one example of possible outcomes of this level of study like was included in updates to NFPA 1141 and NFPA 1144.

9. WORKS CITED

Ahrens, M. (2013). *Home Structure Fires.* Quincy, MA: National Fire Protection Association. Retrieved from http://www.nfpa.org/~/media/Files/Research/NFPA%20reports/Occupancies/oshomes.pdf

Andersson, P., Simonson, M., Rosell, L., Blomqvist, P., & Stripple, H. (2003). *Fire-LCA Model: Furniture Study.* SP Fire Technology. Retrieved from http://www.sp.se/en/index/services/firelca/sidor/default.aspx

Andersson, P., Simonson, M., Tullin, C., Stripple, H., Sundqvist, J., & Paloposki, T. (2004). *Fire-LCA Guidelines.* SP FIre Technology. Retrieved from http://www.sp.se/en/index/services/firelca/sidor/default.aspx

ASTM E917. (2013). *ASTM E 917: Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*. Retrieved from ASTM.org: http://www.astm.org/Standards/E917.htm

Bhargava, M., & Sirabian, R. (2011). *SiteWiseTM Version 3 User Guide.* Navy, NAVFAC EXWC. Hueneme, CA: NAVFAC Engineering and Expeditionary Warfare Center. Retrieved from http://www.navfac.navy.mil/content/dam/navfac/Specialty%20Centers/Engineering%20and%20Expeditionary%20Warfare%20Center/Environmental/Restoration/er_pdfs/s/navfacexwc-ev-ug-1302-sitewise3-20130807.pdf

Blomqvist, P. (2005). *Emissions from Fires.* Doctoral Thesis, Lund University, Department of Fire Safety Engineering, Lund, Sweden. Retrieved from http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=545459&fileOId=545460

Bowick, M., O'Connor, J., & Meil, J. (2014). *Athena Guide to Whole-building LCA in Green Building Programs.* Ottawa, Ontario: Athena Sustainable Materials Institute. Retrieved from http://www.athenasmi.org/wp-content/uploads/2014/03/Athena_Guide_to_Whole-Building_LCA_in_Green_Building_Programs_March-2014.pdf

BRE Global. (2013). *An Environmental Impact and Cost Benefit Analysis for Fire Sprinklers in Warehouse Buildings.* London, England: The Business Sprinkler Alliance. Retrieved from http://www.business-sprinkler-alliance.org/wp-content/uploads/downloads/2014/01/BRE-Report.pdf

Brnich Jr, M., & Kowalski-Trakofker, K. (2010). Underground Coal Mine Disasters 1900 - 2010: Events, Responses, and a Look to the Future. Retrieved from http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/ucmdn.pdf

Bussum, L. (2013). *National Fire Weather Report.* Boise, ID: NWS Fire Weather Operations Coordinator. Retrieved from National Weather Service: http://www.srh.noaa.gov/ridge2/fire/docs/National_Report_2013.pdf

CEGIS. (2014, January). *Center of Excellence for Geospatial Information Science (CEGIS)*. Retrieved from USGS - CEGIS: http://cegis.usgs.gov/

Clinton, N., Gong, P., & Scott, K. (2006). Quantification of Pollutants emitted from very Large Wildland Fires in Southern California, USA. *Atmospheric Environment*, 3686-3695.

CRC. (1999). Environmental Impact Assessment. In *Environmental Engineer's Handbook.* Boca Raton, Fl: CRC Press LLC.

DOE. (2011). *Buildings Energy Data Book.* Silver Spring, Maryland: United States Department of Energy. Retrieved from http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2011_BEDB.pdf

EPA. (1991). *Kuwait Oil Fires: Interagency Interim Report.* Washington, DC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=90050O00.txt

EPA. (1998). *Guidelines for Ecological Risk Assessment.* Environmental Protection Agency. Retrieved from http://www.epa.gov/raf/publications/pdfs/ECOTXTBX.PDF

EPA. (2008, January). *Polycyclic Aromatic Hydrocarbons (PAHs).* Retrieved from Environmental Protection Agency: http://www.epa.gov/osw/hazard/wastemin/minimize/factshts/pahs.pdf

EPA. (2012). *Planning an Ecological Risk Assessment*. Retrieved from EPA Risk Assessment: http://www.epa.gov/risk_assessment/planning-ecorisk.htm

Evans, D., Madrzykowski, D., & Haynes, G. (1994). *Flame Heights and Heat Release Rates of 1991 Kuwait Oil Field Fires.* NIST. Ottawa, Ontario, Canada: Fire Safety Science. Retrieved from http://fire.nist.gov/bfrlpubs/fire94/PDF/f94064.pdf

Evarts, B. (2012). *Fires in U.S. Industrial and Manufacturing Facilities.* Quincy, MA: National Fire Protection Association. Retrieved from http://www.nfpa.org/research/reports-and-statistics/fires-by-property-type/industrial-and-manufacturing-facilities/fires-in-us-industrial-and-manufacturing-facilities

FAO. (2013). *Climate Change Guidelines for Forest Managers.* Rome, Italy: United Nations.

FM Global. (2010). *Environmental Impact of Automatic Fire Sprinklers.* Norwood, MA: FM Global Research Division. Retrieved from http://www.iccsafe.org/gr/Documents/AdoptionToolkit/FM-Global-EnvironmenmtalImpactAutomaticFireSprinklers.pdf

Grier, J. (1982, December 17). Ban of DDT and Subsequent Recovery of Reproduction in Bald Eagles. *Science*, 1232-1235. Retrieved from jstor.org: http://www.jstor.org/stable/1689001

Hall, J. (2013). *High-Rise Building Fires.* Quincy, MA: National Fire Protection Association. Retrieved from http://www.nfpa.org/~/media/Files/Research/NFPA%20reports/Occupancies/oshighrise.pdf

Hamzi, R., Londiche, H., & Bourmada, N. (2008). Fire-LCA Model for Environmental Decision-Making. *Chemical Engineering Research and Design*, 1161-1166. doi:10.1016/j.cherd.2008.05.004

Health and Safety Commission (c). (2006). *Buncefield Major Incident Investigation.* Retrieved from http://www.endsreport.com/docs/20060713d.pdf

Health and Safety Executive. (1993). *The fire at Allied Colloids Limited. A report of the HSE's investigation into the fire at Allied Colloids Ltd, Low Moor, Bradford on 21 July 1992.* Retrieved from http://www.icheme.org/communities/special-interest-groups/safety%20and%20loss%20prevention/resources/~/media/D3C58AAE7B7D4BF392E3885D728AAC0E.pdf

Health and Safety Executive(b). (1995). *BASF, Wilton, Teeside. 9th October 1995*. Retrieved from Health and Safety Executive Case studies: http://www.hse.gov.uk/comah/sragtech/casebasf95.htm

Holemann, H. (1994). *Environmental Problems Caused by Fires and Fire-Fighting Agents.* IAFSS. Retrieved from http://www.iafss.org/publications/fss/4/61/view

ICC(a). (2012). *International Building Code, 2012*. Retrieved from http://publicecodes.cyberregs.com/icod/ibc/2012/index.htm

ICC(b). (2012). *International Fire Code, 2012*. Retrieved from http://publicecodes.cyberregs.com/icod/ifc/2012/index.htm

IPCC. (2014). *Climate Change 2014 Synthesis Report Summary for Policymakers.* New York City, NY: Intergovernmental Panel on Climate Change. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

ISO. (2011). ISO/CD 26367-2 Guidelines for assessing the adverse environmental impact of fire effluents. Retrieved from http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=43529

ISO. (2014). *ISO/TC 207/SC 5 - Life cycle assessment*. (I. O. Standardization, Producer) Retrieved from ISO: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_tc_browse.htm?commid=54854

Karter, M. J. (2014, September). *NFPA* . Retrieved from Fire Loss in the United States During 2013: http://www.nfpa.org/~/media/Files/Research/NFPA%20reports/Overall%20Fire%20Statistics/osfireloss.pdf

Kerber, S. (2010). *Impact of Ventilation on Fire Behavior in Legacy and Contemporary Residential Construction.* Northbrook, IL: Underwriters Laboratories. Retrieved from http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/ventilation/DHS%202008%20Grant%20Report%20Final.pdf

Lippiatt, B., Greig, A., & Lavappa, P. (2010). *BEES*. Retrieved from NIST.gov: http://www.nist.gov/el/economics/BEESSoftware.cfm

Marlair, G., Simonson, M., & Gann, R. (2004). *Environmental Concerns of Fire: Facts Figures, Questions and New Challenges for the Future.* NIST. Retrieved from http://fire.nist.gov/bfrlpubs/fire04/PDF/f04038.pdf

McNamee, M. (2014). Guest Editorial: Fire and the Environment. *Fire Technology*, 1-2. doi:10.1007/s10694-014-0444-z

Modovsky, C. (2007). *Ecological Risk Assessment: Wildland Fire-Fighting Chemicals.* Labat Environmental. Missoula, MT: United States Forest Service. Retrieved from http://www.fs.fed.us/rm/fire/wfcs/documents/era_pub.pdf

Morandini, S., Maher, S., & Schene, R. (1991). Using Fault Tree Analysis to Identify Cost-Effective Design Improvements in Offshore Platform Safety Shutdown Systems. In R. Cox, & M. Walter, *Offshore Safety and Reliability* (pp. 201-211). New York, NY: Elsevier Science Publishing.

National Interagency Fire Center. (2014). *Federal Firefighting Costs (Suppression Only).* Retrieved from National Interagency Fire Center: https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf

Nelson, G. (2000). Fire and Pesticides, A Review and Analysis of Recent Work. *Fire Technology*, 163-183. Retrieved from http://link.springer.com/article/10.1023/A%3A1015462710856

New Zealand Fire Service. (2001). *The Ecotoxic Effects of Fire-Water Runoff: Part I: Literature Review*. Retrieved from http://www.fire.org.nz/Research/Published-Reports/Documents/2a6e4acb13e45a94afef2c9550adbd24.pdf

NFPA. (2012). NFPA 1: Fire Code Handbook. Quincy, MA, USA: NFPA.

NFPA. (2013, 10). *Largest Loss Wildland Fires*. Retrieved from NFPA Reports and Statistics: http://www.nfpa.org/research/reports-and-statistics/outdoor-fires/largest-loss-wildland-fires

NFPA. (2013, April). *Structure Fires by Occupancy 2007-2011- Annual Averages* . Retrieved from NFPA: http://www.nfpa.org/~/media/files/research/nfpa-reports/occupancies/osstructurefiresoccupancy.pdf?la=en

NIFC. (2014, September). *National Interagency Fire Center Year-to-date statistics*. Retrieved from National Interagency Fire Center: http://www.nifc.gov/fireInfo/nfn.htm

Nolter, M., & Vice, D. (2004). Looking back at the Centralia coal fire: a synopsis of its present status. *International Journal of Coal Geology*, 99-106. doi:10.1016/j.coal.2003.12.008

ODUSD(I&E). (2013). *Streamlined Life Cycle Assessment Process for Evaluating Sustainability in DoD Acquisitions.* DOD, Office of the Deputy Under Secretary of Defense (Installations & Environment). Department of Defense. Retrieved from http://www.denix.osd.mil/esohacq/upload/OSD-ATL-SLCA-Guidance_Draft_v1-2_OCT-2013.pdf

Pennsylvania Department of Environmental Protection. (2013). *The Centralia Mine Fire Frequently Asked Questions/Answers*. Retrieved from PDEP: http://files.dep.state.pa.us/Mining/Abandoned%20Mine%20Reclamation/AbandonedMinePortalFiles/Centralia/CentraliaFrequentlyAskedQuestions.pdf#nameddest=B

Ramachandran, G., & Charters, D. (2011). *Quantitative Risk Assessment in Fire Safety*. New York, NY: Spon Press.

Salisbury, H. (1988, October 1). *The Breath of the Black Dragon in Russia and China*. Retrieved from New York Times: http://www.nytimes.com/1988/10/01/opinion/the-breath-of-the-black-dragon-in-russia-and-china.html

Simonson, M., Andersson, P., & Blomqvist, P. (2005). Environmental Assessment of Fires in Products Using the Fire-LCA Model. *FIRE SAFETY SCIENCE–PROCEEDINGS OF THE EIGHTH INTERNATIONAL SYMPOSIUM* (pp. 1071-1082). Beijing, China: International Association for Safety Science. Retrieved from http://www.iafss.org/publications/fss/8/1071/view

Simonson, M., Andersson, P., Rosell, L., Emanuelsson, V., & Stripple, H. (2001). *Fire-LCA Model: Cables Case Study.* SP Swedish National Testing and Research Institute. SP Fire Technology. Retrieved from http://www.sp.se/en/index/services/firelca/sidor/default.aspx

Simonson, M., Blomqvist, P., Boldizar, A., Moller, K., Rosell, L., Tullin, C., . . . Sundqvist, J. (2000). *Fire-LCA Model: TV Case Study.* SP Technical Research Institute of Sweden. Retrieved from http://www.sp.se/en/publications/Sidor/Publikationer.aspx?PublId=537

Turekova, I., & Balog, K. (2010). The Environmental Impacts of Fire-Fighting Foams. *Faculty of Materials Science and Technology in Trnava*, 111-120.

USDA. (2002). *Wildland Fire in Ecosystems: Effects of Fire on Air.* Rocky Mountain Research Station: United States Deparment of Agriculture. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_gtr042_5.pdf

USDA. (2005). *Wildland Fire in Ecosystems: Effects of Fire on Soil and Water.* Rocky Mountain Research Station: United States Department of Agriculture.

USDA. (2013). *Wildfire, Wildlands, and People: Understanding and Preparing for Wildfire in the Wildland-Urban Interface.* Washington DC: United States Department of Agriculture. Retrieved from http://www.fs.fed.us/openspace/fote/wildfire-report.html

USFA. (1987). *Sherwin-Williams Paint Warehouse Fire.* United States Fire Administration. Retrieved from http://www.usfa.fema.gov/downloads/pdf/publications/tr-009.pdf

USFS. (2013, October). *Forest Vegetation Simulator (FVS)*. Retrieved from United States Forest Service: http://www.fs.fed.us/fmsc/fvs/

USFS. (2015, January). *Fire Detection GIS Data*. Retrieved from USFS - Remote Sensing Applications Center: http://activefiremaps.fs.fed.us/gisdata.php

Wildland Fire Assessment System. (2010). *NDFD Fire Danger Point Forecast Tool.* Retrieved from USFS-WFAS: Wildland Fire Assessment System: http://www.wfas.net/

APPENDIX A: GLOBAL REVIEW OF ENVIRONMENTAL IMPACT ASSESSMENT LEGISLATION

Environmental Policy is typically broken down into the different pathways that the environment is exposed to stressors (hazards). These are:

- Air Quality
- Surface Water Quality
- Ground Water Health
- Soil Health
- Solid Waste Management
- Food Safety

Additionally there is legislation that focuses on the Environmental Impacts itself, which typically requires an environmental impact statement (EIS) to prove that the environmental impact will be limited. This is a better quantification of the

Historically environmental legislation is difficult to implement because it is not only a local issue, but also a regional issue as well as global issue. Global groups like the United Nations greatly assist in unifying the ideas and policies

4. Global Groups
   - United Nations (UN)
     The United Nations provides guidance on their version of an environmental impact assessment through their Economics and Trade Branch that is under the Environment program.
     http://www.unep.ch/etb/publications/enviImpAsse.php

5. Regional Groups
   - Asia
     The Asian Environmental Compliance and Enforcement Network (AECEN) is a collaborative effort across the countries of Cambodia, China, India, Indonesia, Japan, Korea, Laos, Malaysia, Maldives, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, and Vietnam. This regional group works to improve collaboration across the region, but has no documentation of a process to determine the environmental impact of fire.
     http://www.aecen.org/
     http://www.aecen.org/eia-compendium

   - European Union (EU)
     The European Union is a collection of Nations on the European continent. Their legislation was first adopted 25 years ago in 1990
     http://ec.europa.eu/environment/eia/review.htm

6. Countries
   - Australia
     http://www.environment.gov.au/about-us/legislation
   - Canada

https://www.ceaa-acee.gc.ca/

- China
  http://www.npc.gov.cn/englishnpc/Law/2007-12/06/content_1382122.htm
- Egypt
  http://www.eeaa.gov.eg/English/main/eia.asp
- Hong Kong
  http://www.epd.gov.hk/eia/english/register/aeiara/all.html
- India
  http://envfor.nic.in/division/introduction-8
- Ireland
  http://www.epa.ie/monitoringassessment/assessment/eia/#.VMssXv54pcQ
- Malaysia
  http://www.doe.gov.my/eia/wp-content/uploads/2013/06/EIA-Procedure-and-Requirements-in-Malaysia.pdf
- New Zealand
  http://www.nzaia.org.nz/
- Sri Lanka
  http://www.cea.lk/web/index.php/en/environmental-impact-assessment-eia-procedure-in-sri-lanka
- United States
  http://www.epa.gov/reg3esd1/nepa/eis.htm

APPENDIX B: QUANTIFICATION OF FIRE IMPACTS

B-1: METHOD FOR CALCULATING CARBON RELEASED FROM FIRE IN RESIDENTIAL SCALE BUILDINGS

This calculation can demonstrate the environmental impact felt from a fire in a residential occupancy. This calculation can be conducted with data from various publically available sources.

1) Fire Statistics:

World-wide:
International Association of Fire and Rescue Service (CTIF)
http://www.ctif.org/ctif/world-fire-statistics

The Geneva Association
2014: https://www.genevaassociation.org/media/874729/ga2014-wfs29.pdf
2012: https://www.genevaassociation.org/media/186703/GA2012-FIRE28.pdf
2011: https://www.genevaassociation.org/media/186303/GA2011-FIRE27.pdf
2010: https://www.genevaassociation.org/media/186253/GA2010-FIRE26.pdf
2009: https://www.genevaassociation.org/media/186228/GA2009-FIRE25.pdf
2008: https://www.genevaassociation.org/media/186203/GA2008-FIRE24.pdf
2007: https://www.genevaassociation.org/media/186003/FIRE%20%C2%B023%20Newsletter.pdf
2006: https://www.genevaassociation.org/media/15822/FIRE%20N%C2%B022.pdf
2005: https://www.genevaassociation.org/media/15351/FIRE%20N%C2%B021.pdf
2002: https://www.genevaassociation.org/media/186153/GA2002-FIRE18.pdf
2001: https://www.genevaassociation.org/media/186128/GA2001-FIRE17.pdf
2000: https://www.genevaassociation.org/media/186103/GA2000-FIRE16.pdf
1999: https://www.genevaassociation.org/media/186078/GA1999-FIRE15.pdf
1998: https://www.genevaassociation.org/media/186053/GA1998-FIRE14.pdf
1997: https://www.genevaassociation.org/media/186028/GA1997-FIRE13.pdf

By Country:
Australia: http://www.iafss.org/publications/fss/5/643/view
Canada: http://www.ccfmfc.ca/stats.html
Germany: http://www.vfdb.de/
Ireland:
http://www.environ.ie/en/Publications/StatisticsandRegularPublications/FireandEmergencyServices/
New Zealand: http://www.fire.org.nz/About-Us/Facts-and-Figures/Pages/Statistics-Data-Fields.html
South Korea: http://www.nfds.go.kr/fr_pos_0001.jsf
UK: https://www.gov.uk/government/collections/fire-statistics-great-britain#documents
USA: http://www.nfpa.org/research/reports-and-statistics/fires-by-property-type

2) Embodied Carbon Info:
Commercial Concrete: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.3.pdf
Commercial Interior Walls: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.6.pdf
Column and Beam: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.8.pdf
Floor Structures: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.7.pdf
Commercial Exterior Walls: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.2.pdf
Roof Assemblies: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.5.pdf

Commercial Windows: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.1.pdf
Wood Based Roof Assemblies: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.4.pdf
Combined: http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2011_BEDB.pdf

3) Residential Scale Testing Results:

FM Global Study: http://www.iccsafe.org/gr/Documents/AdoptionToolkit/FM-Global-EnvironmenmtalImpactAutomaticFireSprinklers.pdf

The above reports can be combed to develop a calculation to assess the environmental damage due to fire:

$$(Extent\ of\ Fire\ Damage\ [ft^2]) \times \left(Embodied\ carbon\ \left[\frac{CO_2}{ft^2}\right]\right) + (CO_2\ released\ from\ contents) = CO_2\ Released\ from\ fire$$

B-2: AGGREGATE EFFECT OF FIRE

To determine the aggregate environmental impact of all fires in the United States for residential fires, we can use a slightly altered means than what is shown above. We know approximately the number of fires in residential structures each year. When we calculate the effects due to CO_2 in the above (Appendix B-2) we can sum that value across the total number of residential fires in the United States.

One of the issues with this is the absence of knowledge of accurate data regarding the extent to what was burned. It is also expected that the contents are almost completely unknown and would have to be assumed based on generalized experimental data.

To combat this lack of knowledge we can bound the problem using a sensitivity analysis using the variables:

Extent of burning: One room flashes over → Total Loss

Heat release or contents: 0 kW → Living room (5-10 MW) → Total Loss (30 MW???)

We can gather information on the embodied energy of a house from a variety of sources

Contents

Contents: http://en.wikipedia.org/wiki/Embodied_energy

Building Materials

Commercial Concrete: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.3.pdf
Commercial Interior Walls: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.6.pdf
Column and Beam: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.8.pdf
Floor Structures: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.7.pdf
Commercial Exterior Walls:
http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.2.pdf
Roof Assemblies: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.5.pdf
Commercial Windows: http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.1.pdf
Wood Based Roof Assemblies:
http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.6.4.pdf
Combined:
http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2011_BEDB.pdf

APPENDIX C: REVIEW OF SELECTED REFERENCES

1. ENVIRONMENTAL IMPACT OF FIRE

ISO 26367-1

Source: ISO 26367-1: Guidelines for Assessing the Adverse Environmental Impact of Fire Effluents Part 1: General

The scope of the ISO document is to give guidance for the assessment of the adverse environmental impact of fire effluents. The standard is valid for residential, commercial, industrial and agricultural structures as well as fires occurring in road, rail and maritime transport systems. The fire effluents will interact with and cause harm to the environment. The main types of interaction can be summarized as:

- Direct gaseous and particulate emissions to the atmosphere,
- Spread of atmospheric emissions,
- Deposition of atmospheric emissions,
- Soil contamination, and
- Ground and surface water contamination.

The fire causes decomposition of the contents which it encounters through pyrolysis and heat. The yields of the pyrolysized contents is very much dependent on the fire and the especially the speed of the decomposition. Smouldering fires are much different than fires than fires that experience complete combustion. Ventilation limited (ventilation-controlled) fires will produce different effluents than a fire that is fuel limited, with the same contents.

Some of the emissions species are CO, CO2, HCN, NOx and other irritants are most important in terms of the acute toxicology. From an environmental point of view the more significant effluents are species with a high molecular weight and aerosols, specifically polycyclic aromatic hydrocarbons (PAHs) and dioxins. An enclosed fire will typically ignite and grow in a pretty typical pattern as long as there is sufficient fuel and oxygen. First ignition occurs then the fire will enter the growth phase. Then the fire will reach its fully developed stage and depending on the fuel characteristics the fire will travel beyond the enclosed space and/or decay.

The environmental impact of intervention is closely tied to the stage that the fire is at. Typically the best case scenario for a fire department to start intervening is about 8-12 minutes in an urban area. At this time in the development of the fire it has typically put itself out and is contained or significant intervention is needed. If the fire is still in its initial stages it has not emitted significant amounts of harmful effluents and intervention will be confined to the local area. Intervention when the fire is larger will mean that the fire is emitting large amount of high molecular weight organic species and other effluents. Intervening at this point will also cause external environmental impacts depending on the types of intervention selected.

Emissions to the air will cause elevated concentrations of airborne pollutants, increased risk from exposure to airborne pollutants and reduced visibility. Additionally particulate atmospheric emissions result in a reduction in the environmental quality with potential long-term toxicity. PM10 airborne particles with a mass medium aerodynamic diameter of 10 µm or less present a potential hazard due to their effect on the respiratory system and their transport of carcinogenic organic species such as PAHs, dioxins and furans.

The fire zone is the area that the fire is actively burning, whether it be inside a building or as part of a wildfire. The fire plume zone is the area over which the fire disperses. The fire plume zone is affected by the topography of the area and the meteorological conditions at the time of the fire. The plume deposition zone is the region under the fire plume where solids in the plume, are deposited on the terrestrial environment. Health and ecological damage will arise from exposure to deposited pollutants through a variety of pathways such as aerial deposition to water and land and accumulation in the food chain (flora & fauna).

Emissions to the terrestrial environment can occur from direct transmission from the fire or through secondary means, such as effluents traveling through the atmosphere creating acid rain.

Emissions to the water has historically presented the highest risk. Direct run-off of the contaminated fire-fighting water, foam, and chemical agent can significantly interrupt the normal activities of the water way from an ecological standpoint. The extent to which the water environment can be affected is dependent upon a variety of factors including:

- **Physical properties**
  - The volume of the water environment (receptor)
  - The travel time from the fire to the receptor
  - The dilution afforded by the fire environment
  - The temperature of the water environment
  - The chemistry of the water environment
  - Type of water environment
- **Chemical Properties**
  - Chemical properties of the Run-off (stressor)
  - Source of the fire
  - The concentration of suspended solids (soot, ash, etc.)
  - The contents of the fire or fire area
  - The chemicals stored nearby
- **Sensitivity of Receptor**
  - Public drinking water
  - Value of Fisheries
  - Value of Aquatic Ecosystem

The effect of the fire effluents on surface water and groundwater are both significant and require the fire department to include this in their risk management procedures. Surface water pollution is typically caused by run-off (stressor) and is not usually long lasting or serious. However if the surface water pollution can reach a water treatment plant it has the ability to cause significant damage and overload the water treatment plant. If runoff can seem into the ground water it would have the ability to destroy that resource for any drinking water supply.

THE ENVIRONMENTAL IMPACTS

The environmental impacts of fire can be broken down into two categories; short-term impacts and long-term impacts. Short-term impacts are limited to the local environment around the fire, impacted by the fire plume or water run-off and usually is within hours or sometimes days. The short-term impacts are usually acute, like asphyxiate gases and irritant gases. Run-off water with substances of acute toxicity present the highest risk scenario.

Long term environmental impacts are also mainly experienced within the local environment and are associated with the persistent organic pollutants (POPs) and other long-lived toxicants. Additionally things like metals have the potential to be transmitted to the terrestrial environment and then exist there for many years.

Assessing the environmental impact can be challenging depend to what extent and level of detail it needs to be completed to. In order to make an accurate assessment of the impact sampling need to be completed. Sampling of the air can done while the fire is on-going. Collecting the sample from the fire plume either from the air or from the ground is very challenging. Getting samples of soil or water is easier. Once the samples are attained, laboratory work can identify the exact breakdown of impacts on the water.

The following list is comprised of definitions that are directly from the ISO 26367 document. (ISO, 2011). This is included because we feel as though they give good guidance for these terms and want to conform to these terms instead of creating a unique definition.

GLOSSARY OF STANDARD SPECIFIC TERMS

Environment: surroundings within which a fire occurs, including air, water, land, natural resources, flora, fauna and humans, and their interrelation.

- **Local**: within the perimeter of a burning enclosure (this part of ISO 26367 is not applicable to burning enclosures).
- **Immediate**: vicinity within a short distance of, e.g. 1 km from the fire and excluding the local area of an enclosure fire.
- **External**: area outside the immediate vicinity of a fire; the extent of this depends on weather conditions and types of emission, i.e. to air, water or land, with short-term or long-term consequences.

Environmental Impact: any change to the environment, whether adverse or beneficial, wholly or partially resulting from a fire

Major accident: significant emission, fire or explosion resulting from uncontrolled developments in the course of the operation of any establishment, and leading to serious danger to human health and/or the environment, immediate or delayed, inside or outside the establishment, and involving environmentally hazardous materials.

Fire Effluent: all gases and aerosols, including suspended particles, created by combustion or pyrolysis

- **Primary Fire Effluent**: Effluent release directly from the fire source.
- **Secondary Fire Effluent**: Effluent created through interaction between a primary fire effluent and the environment.

Receptors: segments of the environment on which fire effluents can have an impact, including air, water, and soil environments, plus flora and fauna associated with these environments, including humans.
Run-Off: Fluid effluent created through the interaction between a fire and a liquid extinguishing agent and hazardous materials stored or generated on site.
Enclosed fires: Fires which have been ignited and which take place inside an enclosure.

Fires in ruptured enclosures: Fires in enclosures that have been breached and that allow unrestricted emission of the fire smoke plume for environmental distribution.
Unenclosed fires: Fires which initiate and propagate in the open air and those which initiate and propagate within an enclosure that subsequently ruptures and transforms the fire in terms of ventilation conditions and effluent transport mechanisms.

ISO 26367-2

Source: ISO 26367-2: Guidelines for Assessing the Adverse Environmental Impact of Fire Effluents Part 2: Methodology for compiling environmentally significant emissions from fires.

The scope of ISO 26367-2 is to focus on the specific emissions from the fire. This International Standard focuses on the fire effluents that are environmentally significant, both in terms of long-term effects (e.g. persistent organic pollutants, POPs) and short-term effects (e.g. in terms of biotope damage and smog). It is not possible to treat all possible contaminants in fire effluents in this single document and therefore a list of those contaminants specifically addressed in this International Standard is given below:

a) Contaminants with long-term effects: metals, particulates, polyaromatic hydrocarbons (PAHs), dioxins and furans (PXDDs/PXDFs), polychlorinated biphenyls (PCBs), and perfluorinated compounds (PFCs).
b) Contaminants with short-term effects: nitrogen oxides (NOx), sulphur oxides (SOx), metals, and halogenated acids (HXs).

To report an adverse environmental impact there are a number of steps that must be completed to ensure that everything is accounted for.

1. Purpose
   - Assess Damage
   - Forensic Investigation
   - Risk Assessment
   - Environmental Impact Statement (EIS)
   - Life Cycle Assessment (LCA)
2. Scope

- Describe the Scene
- Sampling Viability
- Data Viability

3. Fire
    - Weather
    - Fire Progression
    - Potential Pollutants
    - Sensitivity of Surroundings
    - Exposure Pathways
4. Findings
    - Air
    - Surface Water
    - Ground Water
    - Sediments
    - Soil

2. ENVIRONMENTAL IMPACT ASSESSMENT

CRC Environmental Impact Assessment

Source: Canter, L. W. (1999). Environmental Impact Assessment. In H. F. L. Ed. David & G. L. Bela (Eds.), *Environmental Engineer's Handbook*. Boca Raton: CRC Press LLC. Retrieved from http://www.crcnetbase.com/doi/pdfplus/10.1201/NOE0849321573.ch2

The environmental impact assessment is divided into a number of parts to make it simpler to understand and conduct the assessment. The techniques are made broad enough, so that they may be adapted to the desired purpose of the user. The development of many of the tools to determine the impact to the environment, was a result of the National Environmental Policy Act (NEPA) in 1969.

Environmental Impact Assessment: Systematic identification and evaluation of the potential impacts (effects) of proposed projects, plans, programs, or legislative actions, relative to the physical-chemical-biological, cultural, and socioeconomic components of the environment.

To determine the significance of the event questions that should be asked about the fire:

- Beneficial or detrimental
- Naturally reversible or irreversible
- Repairable via management practices or irreparable
- Short term or long term
- Temporary or continuous
- Construction or operational phase
- Local, regional, national, or global
- Accidental or planned
- Direct (primary) or Indirect (secondary)

Effects (or impacts): These terms can be considered as synonymous. Two broad categories of effects are direct and indirect. Direct effects are caused by the action and occur at the same time and place. Indirect effects are caused by the action and occur later or farther removed in distance, but are still reasonably foreseeable. Indirect effects may include growth-inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems. Effects include ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative. Effects also include those resulting from actions which may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.

Cumulative impact: The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or nonfederal) or person undertakes such other actions. Cumulative impacts can result from individually minor, but collectively significant, actions taking place over a period of time.

To conduct an environmental impact assessment there are several actions that are required to be completed:

- Impact identification,
- Preparation of a description of the affected environment,
- Impact prediction and assessment, and
- Selection of the proposed action from a set of alternatives being evaluated to meet identified needs.

Conduction the EIA requires a mix or a method and a set of actions.

TABLE 7: THE SYNOPSIS OF EIA METHODS AND STUDY ACTIVITIES

Types of Methods in EIA	Define Issues (Scoping)	Impact Identification	Describe Affected Environment	Impact Prediction	Impact Assessment	Decision Making	Communication of Results
Decision-focused checklists (MCDM; MAUM; DA; scaling, rating, or ranking: weighting)					X	X	X
Expert opinion (professional judgment, Delphi, adaptive environmental assessment, simulation modeling)		X		X	X		
Expert systems (impact identification, prediction, assessment, decision making)	X	X	X	X	X	X	
Laboratory testing and scale models		X		X			
Matrices (simple, stepped, scoring)	X	X		X	X	X	X
Risk assessment	X	X	X	X	X		

ECOLOGICAL RISK ASSESSMENT

Source: Environmental Protection Agency. (1998). *Guidelines for Ecological Risk Assessment*. (EPA/630/R-95/002F). Retrieved from http://www.epa.gov/raf/publications/pdfs/ECOTXTBX.PDF.

Environmental Protection Agency (1998). Guidelines for Ecological Risk Assessment.
Conducting an ecological risk assessment has 3 primary phases; problem formulation, analysis, risk characterization. Breaking the steps down further problem formulation consists of four steps:

- Evaluate Goals
- Selector Assessment Endpoints
- Prepare Conceptual Model
- Develop an Analysis Plan

The Second portion of conduction an ecological risk assessment is analysis. The analysis can be broken down into the following steps:

- Characterization of Exposure
- Characterization of Ecological Effects

The last part of the ecological risk assessment is the risk characterization. The risk characterization is broken down into:

- Estimating the risk by integrating the exposure and stressor response profiles
- Describing the risk by discussing lines of evidence
- Determining the ecological adversity

<u>PLANNING AN ECOLOGICAL RISK ASSESSMENT</u>

Risk assessors will typically ask the following questions when planning a human health risk assessment: Who/What/Where is at risk?

- Individual
- General population
- Lifestages such as juveniles or adults
- Population subgroups — highly susceptible (for example, due to genetics) and/or highly exposed (for example, based on geographic area)
- Different species — mink, for example, are highly susceptible to PCBs

What are the environmental hazards of concern?

- Chemicals (single or multiple/cumulative risk)
- Physical (changes to a habitat)
- Microbiological or biological (disease or invasive species)
- Nutritional (for example, fitness or metabolic state)

Where do these environmental hazards come from?

- Point sources (for example, smoke or water discharge from a factory; contamination from a Superfund site)
- Non-point sources (for example, automobile exhaust; agricultural runoff)
- Natural sources

How does exposure occur?

- Pathways (recognizing that one or more may be involved)
    - Air
    - Surface Water
    - Groundwater
    - Soil
    - Solid Waste
    - Food
- Routes (and related human activities that lead to exposure)
    - Ingestion (both food and water)
    - Contact with skin
    - Inhalation

- Non-dietary ingestion (for example, preening/grooming behavior)

What does the body do with the environmental hazard and how is this impacted by factors such as life-stage, genetics, species differences, etc.?

- Absorption — does the body take up the environmental hazard
- Distribution — does the environmental hazard travel throughout the body or does it stay in one place?
- Metabolism — does the body break down the environmental hazard?
- Excretion — how does the body get rid of it?

What are the ecological effects?

Example of some ecological effects include, but are not limited to, changes in reproductive rates, tumors, effects on the nervous system, and mortality.

How long does it take for an environmental hazard to cause a toxic effect? Does it matter when in a lifetime exposure occurs?

- How long?
  - Acute - right away or within a few hours to a day
  - Subchronic - weeks or months (for humans generally less than 10% of their lifespan)
  - Chronic - a significant part of a lifetime or a lifetime (for humans at least seven years)
  - Intermittent
- Timing
  - Is there a critical time during a lifetime when a chemical is most toxic (e.g., fetal or embryonic development, juvenile stages, adulthood)?

The following list is comprised of definitions that are directly from the Environmental Protection Agency (EPA, 1998). This is included because we feel as though they give good guidance for these terms and want to conform to these terms instead of creating a unique definition.

GLOSSARY OF TERMS

Agent: Any physical, chemical, or biological entity that can induce an adverse response (synonymous with stressor).

Assessment endpoint: An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes. For example, salmon are valued ecological entities; reproduction and age class structure are some of their important attributes. Together “salmon reproduction and age class structure” form an assessment endpoint.

Characterization of ecological effects: A portion of the analysis phase of ecological risk assessment that evaluates the ability of a stressor(s) to cause adverse effects under a particular set of circumstances.

Characterization of exposure: A portion of the analysis phase of ecological risk assessment that evaluates the interaction of the stressor with one or more ecological entities. Exposure can be expressed as co-occurrence or contact, depending on the stressor and ecological component involved.

Exposure profile: The product of characterization of exposure in the analysis phase of ecological risk assessment. The exposure profile summarizes the magnitude and spatial and temporal patterns of exposure for the scenarios described in the conceptual model.
Lines of evidence: Information derived from different sources or by different techniques that can be used to describe and interpret risk estimates. Unlike the term "weight of evidence," it does not necessarily imply assignment of quantitative weightings to information.
Lowest-observed-adverse-effect level (LOAEL): The lowest level of a stressor evaluated in a test that causes statistically significant differences from the controls.
Maximum acceptable toxic concentration (MATC): For a particular ecological effects test, this term is used to mean either the range between the NOAEL and the LOAEL or the geometric mean of the NOAEL and the LOAEL. The geometric mean is also known as the chronic value.
No-observed-adverse-effect level (NOAEL): The highest level of a stressor evaluated in a test that does not cause statistically significant differences from the controls.
Receptor: The ecological entity exposed to the stressor.
Source: An entity or action that releases to the environment or imposes on the environment a chemical, physical, or biological stressor or stressors.
Stressor: Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).

ENVIRONMENTAL IMPACT ASSESSMENT

Source: Environmental Protection Agency. (1992). Environmental Impact Assessments (Vol. EPA-600/M-91/037). Washington DC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300024Q1.txt

Environmental Protection Agency (1992). Environmental Impact Assessments. Washington DC, Environmental Protection Agency. **EPA-600/M-91/037**.

Environmental Assessment (EA) Process: This generic term denotes a multifaceted decision-making process. The process is structured to anticipate, analyze and disclose the consequences associated with proposed activities' with respect to established public policies for protecting and enhancing the natural and man-made environment.

The overall purpose for undertaking an environmental assessment is to seek Ways to avoid or minimize adverse effects of a proposed project to the extent practicable, and the maintenance, restoration or enhancement of environmental quality as much as possible.

3. STATISTICS

THE GENEVA ASSOCIATION – WORLD FIRE STATISTICS BULLETIN

Source: The Geneva Association Staff. (2014). World Fire Statistics: Fire and Climate Control. Retrieved from https://www.genevaassociation.org/media/874729/ga2014-wfs29.pdf

This paper looked at the relationship between fire and the various costs associated with fire. This included:

- Costs of direct fire losses
- Costs of indirect fire losses
- Human Fire Losses
- Costs of Fire Fighting Organizations
- Costs of Fire Insurance Administration
- Cost of Fire to protect buildings
- Forests and wildland fires

Because this report was ultimately generated by the insurance industry most of the metrics were reported using a monetary value and the percent of GDP. There were a couple interesting points brought up about wildfires though. First that the "intensity, frequency, and duration of wildfires are now considered to be directly influenced by global warming". Additionally model predictions show that "wildfire seasons by 2050 will be three weeks longer, up to twice as smoky and will burn a wider area in the Western United States."

The paper reports the number of wild land fire incidents for several different countries from 2008 to 2010. Australia has the most incidents by far with almost 45,000 fires occurring in 2009. New Zealand also experiences a lot of fires and it resulted in 15,000 hectares burned in 2008. It also shows the area burnt and summarizes the data by showing the average area burn per incident.

This fits into our project because it gives us data for several countries around the world that have wildfires. It is especially important that we know the number of incidents and the size. If we know the average economic effect of a forest fire we can extrapolate that to fit the effect on the different localities.

CENTER OF FIRE STATISTICS – WORLD FIRE STATISTICS

Source: Brushlinsky, N. N., Ahrens, M., Sokolov, S. V., & Wagner, P. (2013). Center of Fire Statistics: World Fire Statistics. Retrieved from http://www.ctif.org/sites/default/files/ctif_report19_world_fire_statistics_2014.pdf

This report contains statistics on fires from 35 countries and 30 cities. The report is due to a collaboration between the US, Russia, and Germany. The report is very rich with data including the number of fires and the average number of fires per 1000 inhabitants. This data is broken down globally by year and by every nation.

The total number of fires for every year from 1993 to 2012 for the number of countries is reported. Using this information we can show the number of fires recorded in the world. It also benchmarks the number of fires per population which can be used to determine the number of fires in different localities.

The number of fires and the population can be used to show the extent of the fire problem in the countries listed. The study also shows where fires are most likely to occur in each country based on the number of people. This is good for looking at the fire scale that we have identified.
Also reported is the break down as determined by the number of cities instead of by country. These statistics can be used to check whether there is a difference between cities and countries and how that might change the impacts.

WILDFIRES AND AIR POLLUTION: THE HIDDEN HEALTH HAZARDS OF CLIMATE CHANGE

Source: Kenward, A., Adams-Smith, D., & Raja, U. (2013). Wildfires and Air Pollution: The Hidden Health Hazards of Climate Change. Retrieved from http://assets.climatecentral.org/pdfs/WildfiresAndAirPollution.pdf

This paper describes the effect of wildfires on air pollution. The effect of a shorter spring snow melt and longer hotter summers causes the number of large wildfires to double every year, since the 1970s and could grow larger of the next 20 years. The effect of these larger fires is to produce an enormous amount of smoke and air pollution. This pollution decreases the air quality to be 5-15 times worse than normal, in some cases.

Air quality is defined in a large part by the particulate matter in the air. Fires produce dangerous “fine particulates” which are defined as being less than 2.5 microns. These particles cause short term health problems and long term respiratory issues. In comparison dust pollen and mold are about 10 microns. During the fires in southern California during the fall of 2003 the Los Angeles and Riverside areas saw air pollution levels that were unhealthy for everyone.

This paper clearly describes wildfires as having a negative impact to the environment in terms of the air pollution they cause.

4. ENVIRONMENTAL EVENTS CASE STUDIES

KUWAIT OIL FIRES: INTERAGENCY INTERIM REPORT

Source: Environmental Protection Agency. (1991). Kuwait Oil Fires: Interagency Interim Report. Washington, DC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=90050O00.txt

With the assistance of the Saudi and Kuwaiti Governments, the U.S. Interagency Air Assessment Team has been conducting a reconnaissance survey of the fire plumes and their effects in Kuwait and Saudi Arabia since March 10/1991. The primary objective of, the team was to obtain preliminary, short-term data on the emissions from the smoke emanating from the oil well fires at a variety of locations in order to:

1. Determine if there is an acute health threat associated with the Hydrogen Sulfide (H2S) and Sulfur Dioxide (SO2) and particulates, three pollutants that might be emitted from burning oil wells;
2. Identify and quantify the gaseous and particulate byproducts being produced front the burning oil wells; and
3. Determine if materials associated with these fires are affecting areas where American citizens are located.
4. Assess the potential extent of the health effects related to the emissions from the fires and the status of the Kuwaiti and Saudi health infrastructure.

Based on these objectives, limited, real-time data was obtained directly from the Kuwait oil fields, as well as from Kuwait and Saudi Arabia locations where embassy officials, troops, and citizens work and reside.

Additionally, the Team conducted a number of interviews with health officials to evaluate the extent of acute respiratory problems related to smoke exposure. While only a cursory assessment is possible at this point, some data obtained by the team were encouraging. The preliminary findings are as follows:

1. Limited sampling did not reveal the existence of high concentrations of sulfur dioxide or hydrogen sulfide near the burning wells or in population areas in the path of the oil well emissions;
2. High levels of particulate were found in the air;
3. The results of the current monitoring findings and health interviews with medical personnel in the affected areas suggest that at the present time susceptible subpopulations, such as individuals with asthma and chronic obstructive lung disease, may experience exacerbation of their symptoms. Special health concerns, warnings, advisories, and precautions are clearly warranted for these individuals. This situation does not appear to be life threatening under current exposure conditions but, if meteorological conditions change, i.e., poor air mixing or plume touchdown, there could be adverse health effects for these susceptible individuals; and
4. The long-term effects on health are not readily ascertainable at this time due to insufficient data on the populations exposed, the composition of the smoke plume, the impact of oil pools, and long-term meteorological patterns. Both the Kuwaiti and Saudi health communities have expressed great interest in obtaining training and support from the US medical community that

can be continued by themselves in future years. Aggravating the problem is the severe damage done to the scientific infrastructure of Kuwait thus limiting the current in-country analytic capabilities. Any response by the US would have to include both training and equipment.

To conduct the air monitoring of the fires the following steps were taking.

- Immediate steps would be taken to collect and analyze meteorological observations and forecasts, record visual observations of the smoke plume, and review existing
- Monitoring data. Plume observations via satellite would be obtained daily,
- Supplemented by periodic on-scene aerial transects designed to characterize the overall
- Geometry of the plume.

A ground-based sampling network of portable equipment would be installed by EPA and others at approximately 15-20 locations to measure particulate matter less than 10 microns in diameter (the particle size most likely to penetrate deeply into the lungs).

The ratio of the less than 10 micron particles to total particulate load would be established. Limited organic analysis would be undertaken.

Measurements of carbon monoxide, carbon dioxide, methane, hydrogen sulfide, sulfur dioxide, particle size distribution, elemental and organic carbon, metals, polycyclic aromatic hydrocarbons and acid aerosols would be obtained close to the fires by NASA and NIST. These measurements should attempt to characterize and categorize emissions from several specific wells.

Specially equipped aircraft from the University of Washington (April 15 to May 15), NCAR (May 1 to June l) and NOAA (July 1 to August l) would be deployed to measure downwind plume composition and dispersion, radiative properties and climatic effects, and effects on clouds and precipitation. On the basis of the initial aircraft results, a longer-term sampling program would be designed to monitor the relaxation of the atmospheric environment as the fires are extinguished.

ENVIRONMENTAL CRISIS IN THE GULF

Source: Environmental Protection Agency. (2010). *Environmental Crisis in the Gulf: The U.S. Response*. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100K6UO.txt.

The Kuwait Oil Fields were fist ignited in March by the retreating Iraqi army. With the help of the international community the fires were able to be extinguished by March 1990.

The prevailing winds from the north and breezes off the gulf generally kept the plumes aloft and moving south, over the desert away from Kuwait City, the nearest population center. The smoke dimed sunlight and caused cooler temperatures in the region because of the sunlight being blocked. Bahrain experienced its coldest May in 35 years with temperatures more than 7.2 ° F below average for this month.

Combustion products from the fires were detectible outside of the region and remained in the atmosphere for several weeks.

EFFECT ON GLOBAL CLIMATE

One of the concerns with the long-term oil fires was the effect on the global climate. There was no evidence to shows that the fire plumes rose to high enough altitudes to reach the stratosphere where high-altitude winds could disperse effluents around the globe. From satellite images and observations the oil fires rose to altitudes of 12,000 to 13,000 feet with a maximum of 19,000 feet, well below the stratosphere at 40,000 feet. To compare the oil fires to another event the relative comparison of the oil fire plume from the Kuwait oil fires compared to the Mt. Pinatubo volcanic eruption, because the effluents from the volcano reached the stratosphere the particulate matter will reside in the atmosphere for years.

In the first months after the fires were set, the fires were adding carbon dioxide to the atmosphere at three percent of the world wide industrial emission rate. This was too small and temporary to contribute significantly to the worldwide greenhouse effect.

HEALTH EFFECTS

The air quality measurements taken while the fires were burning did not show any acute threat to the general population. The hazard is the fine particles that are produced by all fires that pose a hazard to those with reduced lung health. The main effluents that were found in the fire plumes by the U.S.

Interagency Air Assessment Team (USIAAT) were soot particles, organic compounds, trace metals, sulfur doxide, hydrogen sulfide, and carbon monoxide. The effluents denoted as the most hazardous are hydrogen sulfide, sulfur dioxide, and fine soot particles because of their effects to human health.

OIL SPILL

The other part of the environmental impact was the six to eight million barrels of oil that the Iraqi Army dumped into the Gulf. The United States sent a Coast Guide led team to formulate an appropriate response. The slick covered almost 600 square miles.

Containment booms were used to prevent the oil from effecting the desalination plant. After the oil was contained, attempts were made to recovering as much of the oil as possible. Almost 1.4 million barrels of oil were recovered. One third of the oil is estimated to have evaporated, and the remainder is assumed to have sunk to the bottom of the ocean.

Significant amounts of oil from this spill and other have washed up on the coast. The oil has threatened the rich ecosystem that surrounds the gulf, including the salt marshes, mangrove swamps, beds of sea grass

SHERWIN-WILLIAMS PAINT WAREHOUSE FIRE

Source: United States Fire Administration. (1987). Sherwin-Williams Paint Warehouse Fire. Retrieved from http://www.usfa.fema.gov/downloads/pdf/publications/tr-009.pdf

The Sherwin-Williams Paint Warehouse fire occurred in Dayton, Ohio on May 27, 1987. The fire started when an employee accidently created a small spill with a forklift and it is thought that the engine on the forklift provided the spark.

The building was of non-combustible construction and was sprinklered. The contents of the warehouse was over 1.5 million gallons of paints and other chemicals. The building was built over the aquifer for the town.

The fire quickly overpowered the sprinkler system in the warehouse and by the time the fire incident command was set up it was known that the warehouse would be a total loss. The incident commander was aware of the environmental issues regarding the aquifer and consulted with the town's water and air experts. They decided that they would not try to extinguish the fire at all, but solely ensure that the fire did not spread to other buildings.

The decision to not try to extinguish the fire saved the town from an environmental disaster which would have affected almost half a million people. There was some water from the sprinkler system and other sources that made it to the nearby Miami River. The dissolved paint solvents that made it to the river were able to be contained and skimmed off of the river. Little ground contamination was found.

The current generation of fire chiefs must be effective risk managers in addition to their knowledge of fire. When a fire department responds to a call they should be away of what the consequences of their actions and inactions are. As part of this consideration the risk management of an emergency event should include the following considerations:

- Characteristics of materials and chemicals involved
- Air versus water pollution
- Wind and weather conditions
- Capability to extinguish or control the fire;
- Ability to contain run-off
- Short-term versus delayed hazards
- Life safety and property exposure
- Evacuation problems.

Water pollution was the main hazard identified for the warehouse fire and it was properly management, but this should be a consideration of every fire department. Fire departments must also be aware that there may be situations where the fire does need to be extinguished because the air pollutants would be significantly worse.

The other concern for fire departments is that any action that they conduct that would discourage typical extinguishment activities may be cause for a law suit from the owner or the owner's insurer. Whether this is a certainty will depend on the situation and whether the municipality has laws that limit or prevent any suit against the fire department.

SANDOZ

The Sandoz Chemical Plant and storage facility near Basel, Switzerland had a fire event on November 1, 1986. The construction of the warehouse was minimum and only designed to provide protection from the elements. The warehouse was built in 1967 and was approximately 295 feet long by 82 feet wide.

The building where the fire started contained approximately 1,250 tons of chemicals in barrels high. The contents of the chemicals was mainly flammable liquids, including pesticides, fungicides, and herbicides. Some of the chemicals included, had a flashpoint of 30°C. Additionally some of the materials that were present were ferric ferrocyanide, phosphoric acid, and organic mercury compounds.

The fire was discovered when flames were shooting out of the roof of the warehouse. The local chief who arrived called in approximately 200 fire fighters from the surrounding fire. Initially the concerns were the spread to other nearby warehouses as well as the toxicity of the gasses going into the atmosphere and their effect on people in the nearby town.

The hazards that were considered led the fire department to attempt to extinguish the fire with as much water as they could pull from the river. At the fires peak almost 8,000 gallons of water per minute was being pumped from the Rhine. The facility did have a 12,000 gallon catch basin to collect water and chemical, but at the rate the water was being administered the catch basin quickly overflowed.

From the location of the warehouse there was 520 miles of river that the fire runoff traveled down until it emptied into the North Sea. The river forms a border between the countries of Switzerland, France, Germany, Luxembourg, Belgium, and the Netherlands. Because of this the fire event turned into an international ecological disaster. Within a week, half a million fish were killed and the chemicals made life impossible in large stretches of the river. In addition heavy metals that sunk to the bottom of the river continue to be stirred up releasing pollution over time.

The enormity of the event forced the study of fire prevention and environmental protection. The confluence of these two fields, especially when potentially harmful chemicals are present were not considered part of the each other’s risk management strategy and would need to be re-evaluated. Included in this is the proper use of labels and the understanding of what the hazards and risks are if there was to be a fire or other disaster.

The design of buildings containing hazardous chemicals were rethought. First, it was obvious that the catch basis for runoff was grossly inadequate and further study on what catchment size is appropriate is needed. Second is the design of the fire prevention system and how to adequately provide protection for high hazard contents like were in the Sandoz warehouse.

MASS CASUALTY CHEMICAL INCIDENTS

Source: Murray, V., & Goodfellow, F. (2002). Mass Casualty Chemical Incidents - Towards Guidance for Public Health Management. *Public Health, 116*(1), 2-14. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11896630
http://www.sciencedirect.com/science/article/pii/S0033350602900533

Abstract:

Two main topics are covered in this article, (1) a review of mass casualty chemical incidents occurring naturally or as a result of industrial activities or deliberate release provided an opportunity to consider the problems experienced in medical and public health response, and (2) a literature review of procedures to assist in the management of chemical incidents by medical and public health professionals was conducted, targeted at summarizing what tools exist to minimize the impact on public health from such events. It was found that the most of the large chemical incidents worldwide were unprecedented and unexpected, and as a consequence emergency services, hospitals and public health had access to very little relevant information in the first few hours. Several lessons were highlighted that would aid future response. The review of procedures showed that there are currently no written procedures that are both sufficiently generic and sufficiently detailed to effectively support the public health management of the emergency response to chemical incidents. There is therefore a need to fill this obvious gap and to develop a procedural guide for the emergency management of chemical incidents by public health professionals.

Highlights:

Table 1 – Naturally occurring chemical releases
Table 2 – List of worldwide mass casualty industrial and transport chemical incidents where more than 25 were killed and more than 100 were injured between 1975 and 1999.
Table 3 – Significant mass casualty industrial chemical incidents where more than 25 were killed and more than 100 were injured before 1975 and after 1999.
Table 4 – Significant mass casualty deliberate chemical incidents

Applicability to Project:

This article included multiple tables about incident information associated with chemicals release to the environment and number of death / injuries.

PHILLIPS PETROLEUM CHEMICAL PLANT EXPLOSION AND FIRE

Source: Yates, J. (1989). Phillips Petroleum Chemical Plant Explosion and Fire: U.S. Fire Administration. Retrieved from http://www.usfa.fema.gov/downloads/pdf/publications/tr-035.pdf

Abstract:

During the course of operations at the Phillips Petroleum Houston Chemical Complex in Pasadena, Texas, on October 23, 1989, an explosion and ensuing fire occurred which resulted in 23 known dead and one missing. In addition, more than 100 other people were injured in varying degrees. Metal and concrete debris was found as far as six miles away following the explosion.

There was a failure in either a line or valve which carried ethylene and/or isobutene. The line was reported as being approximately 10 inches in diameter and possibly carrying as much as 700 pounds per square inch pressure. It is not known if a mechanical failure took place or if human error was a factor. Information from witnesses indicates that a vapor cloud developed very quickly and that workers had approximately 60 to 90 seconds to evacuate. Potential ignition sources were all over the plant, including ventilation fans, electrical switches, and gas burn-off flames throughout the work area. Early estimates of rebuilding efforts indicated that costs could run to four or five hundred million dollars and rebuilding may take as long as two years.

Highlights: Environmental Impact Awareness

Fuels involved in the fire produced no toxic problem with the smoke being emitted at the time. However, as a precaution, they had gone to a Level 2 Community Awareness Emergency Response (CAER) Alert. This was a Standby Alert, indicating that an industrial accident is in progress but appears it can be handled within the boundaries of the facility. However, outside areas could be affected. Accordingly, CIMA was prepared to handle an outside alert if needed. Results of smoke samples that were taken during the fire by the Occupational Safety and Health Administration (OSHA) or others were unknown at the time of this report.

Applicability to Project:

Based on the limited information, this article mentioned that there was a minimum impact on the environment regarding the size of the accident. I’m not sure if this report will be useful.

UNCONTROLLED COAL FIRES AND THEIR ENVIRONMENTAL IMPACTS: INVESTIGATING TWO ARID MINING REGIONS IN NORTH-CENTRAL CHINA

Source: Kuenzer, C., Zhang, J., Tetzlaff, A., van Dijk, P., Voigt, S., Mehl, H., & Wagner, W. (2007). Uncontrolled Coal Fires and Their Environmental Impacts: Investigating Two Arid Mining Regions in North-central China: Applied Geography. Retrieved from http://www.sciencedirect.com/science/article/pii/S0143622806000142

Abstract:
Uncontrolled coal fires occur worldwide and pose a great threat to the environment. This paper introduces the problem of coal fires referring to two coalfields in north-central China. These areas were regularly investigated during numerous fieldwork campaigns between 2002 and 2005. New approaches for coal fire research are undertaken in numerous national and multi-lateral projects. Research disciplines, addressing the problem of coal fires, include geography, geology, geo-physics, mining engineering, and remote sensing. In combination, they lead the direction towards a holistic approach to detect, monitor, quantify, and finally extinguish the coal fires.

Highlights:

Impact of coal fires on recent geology and geomorphology
A local geologic phenomenon resulting from coal fires is the occurrence of pyrometamorphic rocks. These are rocks, which were baked or heated by coal fires resulting in texture- and colour changes due to oxidation and dehydration. The original rocks can be transformed into only slightly pyro-metamorphised baked rock or into heavily pyro-metamorphosed brecciated or molten rock, showing the characteristics of lava due to the increase of temperature

Impact of gaseous coal fire emissions on atmosphere and human health
Coal fires release heavy smoke, rich of carbon-monoxide (CO), carbon-dioxide (CO2), methane (CH4), sulphur-dioxide (SO2), nitrous oxides (NOx) and other green-house- or toxic gases (e.g. H2S, N2O) as well as fly ash from vents and fissures. Chemical calculations indicate, that complete burning of 1 ton of average quality coal leads to an emission of 1.17 ton of CO2 and 0.17 ton of methane, with the latter having a 23-fold higher greenhouse capability than CO2. This means that 1 kg of methane in the atmosphere contributes 23 times stronger to atmospheric warming (greenhouse effect) than 1 kg of CO2.

Impacts of coal fires on vegetation
It was observed, that the vegetation density in coal fire areas is decreased within the Wuda coal-mining syncline during the fieldwork in 2002 and 2003. The toxic gasses and the underground heat are responsible for the deterioration of vegetation located above the underground fires. Here, vegetation density is often reduced to less than five percent, with no vegetation at all or only dead vegetation remaining within the close association of the fires.

ENVIRONMENTAL CONCERNS OF FIRES:

Source: Marlair, G., Simonson, M., & Gann, R. G. (2004). Environmental Concerns of Fires: Facts Figures, Questions, and New Challenges for the Future. *Interflam, 1*, 325-337. Retrieved from http://fire.nist.gov/bfrlpubs/fire04/PDF/f04038.pdf

Abstract:
This paper presents a discussion of the accident (the Sandoz facility in Schweizerhalle in November 1986) together with a representative sample of other environmentally important case studies related to fires. Modes of interaction with the environment and potential transfer mechanisms are discussed. The impact of fire effluents in both the short and long terms and activities on the quantification of the environmental effect of fires are also presented. Some of the current environmental debates that are interacting with fire prevention and firefighting techniques are also discussed, outlining challenging remaining issues. Finally, insight on international action in response to these incidents and related standardization activities under progress is presented.

Highlights:
Chemical fire incident near Basel Switzerland in November 1986
The fire presented major challenges in terms of firefighting tactics, emergency response management, crisis communication with concerned nearby countries (France and Germany), air pollution in a highly urbanized area, and water pollution. Large amounts of extinguishing water contaminated by pesticides and other toxic materials ran off directly into the river Rhine, killing aquatic life for several hundreds of kilometers.

QUANTIfiCATION OF POLLUTANTS EMITTED FROM VERY LARGE WILD LAND fiRES IN SOUTHERN CALIFORNIA, USA

Source: Clinton, N. E., Gong, P., & Scott, K. (2006). Quantification of Pollutants Emitted from Very Large Wildland Fires in Southern California, USA. 3686-3695. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231006002135

A study done in 2006 looked at using a model to estimate the effluents from large wildfires. Several large fires that burned in Southern California during the summer of 2003 provided the necessary real data to supplement the model.

The model, referred to as the First Order Fire Effects Model (FOFEM) used several inputs to find the quantified values for the outputs.

Inputs

- Geographic Information System (GIS) data
- Vegetation Data
  - Fuel Model Data
  - Duff
  - Litter
  - Herbs
  - Shrubs
  - Tree Regeneration
  - Live Branch-Wood
  - Live Foliage
- Weather Condition Data
- Fire Perimeters

Outputs (pounds):

- 10 µm Particulates
- 2.5 µm Particulates
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Methane (CH_4)
- Non-Methane Hydrocarbons
- Ammonia (NH_4)
- Nitrous Oxide (N_2O)
- Oxides of Nitrogen (NO_x)
- Sulfur Dioxide (SO_2)

From this information, using the southern California fires as the focus the model estimated that over 5 million metric tons (megagrams) of total pollutant emissions over several days. These emissions include over 457,000 tons of carbon monoxide, over 6 million tons (approximately 6 Tg) of carbon dioxide, and over 46,000 tons of particulates. Fuels that contributed the most mass to the fire emissions were predominantly shrubs and duff. Wildfires can have an impact at a continental scale, intercontinental scale, and affect air quality at locations distant from the source.

The goal of this paper is to go beyond the simple analysis that the EPA provides with their emissions factor equation. The general equation is

$$E = A \times EF \times \left(1 - \frac{ER}{100}\right)$$

E= emissions
A=Activity rate
EF=Emission factor
ER=Overall emission reduction efficiency, %

This uses data from AP-42, Compilation of Air Pollutant Emission Factors to calculate the emissions. . This method calculating the emissions utilizes many assumptions and provides less precision than a model such as FOFEM.

The use of spatially based emissions estimation models, unlike the simple model the EPA suggests presents a more precise representation of the actual effluents given off from a fire. This model uses inputs from various sources and could provide useful information on an hour by hour basis if accurate information could be provided. The use of this model is to provide information for air quality management, mitigation of wild land fire environmental effects, and identification of wildland fire emission signatures. In addition there is significant innovation on remote sensing capabilities and the fire effects models can feed into the remote sensing models and vice-versa to improve the capabilities of both.

5. ENVIRONMENTAL STUDIES OF BUILDING FIRES

ENVIRONMENTAL PROBLEMS CAUSED BY FIRES AND FIRE-FIGHTING AGENTS

Source: Holemann, H. (1994). Environmental Problems Caused by Fires and Fire-Fighting Agents. *Fire Safety Science - Proceedings of 4th International Symposium*, 61-77. Retrieved from http://www.iafss.org/publications/fss/4/61/view

Paper calls for the use of life-cycle analysis to analyze the "new" goal of avoiding environmental damage in addition to protecting life and property. Changes were bought about by the realization that halons were depleting the ozone and a fire at a chemical warehouse in Schweizerhalle near Basel, Switzerland. The runoff from the fire contaminated the River Rhine as well as seeped into the ground. The event caused one of the biggest international environmental catastrophes in history, by all but destroying the river. This paper provides a detailed description of the effluents of the fire as well as typical volatile products of the fire at different temperatures. Paper goes over major fires that have had an impact on the environment as well as extinguishment agents.

An increasing awareness focusses on the environmental impacts of fire suppression activities. The global dimensions of environmental pollution originating from major incidents as well as from natural fires are depicted. The banning of Halons because of their ozone depleting potential is explained. Initiated by a fire in a chemical warehouse, Central Europe's interest concentrates on the retention of contaminated extinguishing water. Finally, remediation strategies for fire related environmental pollution are discussed.

Highlights:
Oil well fires during the Gulf war caused atmospheric pollution caused by the burning of oil wells following the Kuwait-conflict in 1991.

Large forest fires

Particularly the countries in the tropical and sub-tropical hemisphere as well as the new states emerging from the former Soviet Union lack reliable data and statistics on the annual destruction of forest due to natural or anthropogenic fires. Data that is gained by satellite monitoring is not satisfactory either. Some satellites lack the necessary sensing devices whereas other satellites do not provide sufficient observation time or frequency.

The following quantities of carbon are released in tropical and non-tropical areas per year approximately**:**

1. deforestation 1.08 * 1015 t
2. savannah fires 1.66 * 1015 t
3. fire wood 0.88 * 1015 t
4. agricultural waste (straw etc.) 0.38 * 1015 t
5. charcoal production 0.08 * 1015 t

This amounts to 4.08 * 1015 tons of emitted carbon through biomass burning. The overall quantity of carbon dioxide is approximately 13.28 * 1015 t, about 40 per cent of which is generated during combustion of biomass and fossil fuel.

Furthermore tropical biomass burning produces photochemical smog, consisting of CO, NOx and various hydrocarbons. Ozone is generated through a chemical reaction chain. In January 1991 a concentration of approximately 95 ppb ozone was measured at an altitude of 2000 m above an African savannah area. Even higher concentrations where found above the East Atlantic. It is expected that these high concentrations can be traced to the frequent savannah fires in West Africa.

Building Sustainability and Fire-Safety Design Interactions: Scoping Study

Source: Robbins, A. P. (2012). Building Sustainability and Fire-Safety Design Interactions: Scoping Study. Retrieved from http://www.branz.co.nz/cms_show_download.php?id=716733515027fe4626188881f674635d51e3cfb0

The scoping report from BRANZ comments on the trend towards sustainability in the built environment. The argument is to refrain from considering sustainability and fire protection objectives individually and think about them holistically. Considering both objectives can increase the sustainability of the building by decreasing the effects of a fire event through decreased carbon emissions, decreased firefighting operations, limited post-fire clean-up, and better building recovery and re-use. Some environmental impacts resulting from the built environment include: Climate change, ozone depletion, soil erosion, desertification, deforestation, eutrophication, acidification, loss of biodiversity, land, water, air pollution, dispersion of toxic substances, and depletion of resources. The document includes many methodologies for applying sustainable principles.

Impact of Fire Service Activity on the Environment

Source: Moore, S., Burns, B., O'Halloran, K., & Booth, L. (2007). Impact of Fire Service Activity on the Environment (Vol. LC0607/098). Wellington, New Zealand: Landcare Research. Retrieved from http://www.fire.org.nz/Research/Published-Reports/Documents/5b4467e712133823ca35d26c80e6386e.pdf

This research report aimed to understand the impact of fire-fighting operations on the environment and to determine the pollutants generated by fire-fighting activities. The research highlighted a series of fire control and effluent management tactics that could be implemented to minimize the effect of the pollutants. One of the findings was that the fire water often can contain contaminants and pollutants and should be prevented from entering the normal water system, where possible. This report addresses the impact to the water, but not contamination from the plume, or impact form fire to the ground.

ENVIRONMENTAL IMPACT OF AUTOMATIC FIRE SPRINKLERS: PART 1 & 2

Source: Gritzo, L. A., Bill Jr, R. G., Wieczorek, C. J., & Ditch, B. (2011). Environmental Impact of Automatic Fire Sprinklers: Part 1. Residential Sprinklers Revisited in the Age of Sustainability. - *Fire Technology, 47*(3), 751-763. doi: 10.1007/s10694-010-0191-8. Retrieved from - http://dx.doi.org/10.1007/s10694-010-0192-7

Source: Wieczorek, C. J., Ditch, B., & Bill Jr, R. G. (2010). Environmental Impact of Automatic Fire Sprinklers: Part 2. Experimental Study. *Fire Technology*, 765-779. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-010-0192-7

FM Global has conducted a study to quantify the reduction in the environmental impact of fire through the use of automatic fire sprinklers. Large scale fire tests were conducted using identically constructed and furnished residential living rooms with and without sprinklers. The results between the sprinklered and non-sprinklered testes were compared in terms of total greenhouse gas production, quantity of water required to extinguish the fire, quality of water run-off, potential impact of wastewater runoff on groundwater and surface water, and mass of materials requiring disposal. These categories were used to quantify the potential impact of fire on the environment and the environmental benefit of automatic fire sprinklers.

Test rooms were instrumented with ceiling and elevation thermocouples, heat flux gages, and gas measurements, which were calibrated in accordance with ISO/IEC 17025-2005. Gas measurements were made to evaluate the generated combustion products during the fire tests, such as greenhouse gases and pollutants, and also the chemical heat release rate and total energy release. The external instrumentation included measurements on criteria pollutants, volatile organic compounds (VOCs), greenhouse gas pollutants, particulate matter, heavy metals, semi-volatile organic compounds (SVOCs), other organic and inorganic compounds, total hydrocarbons and oxygen. A special water collection system was constructed to collect portion of the water exiting the living room to analyze the contents in the water runoff. The analysis of the water samples included general chemistry parameters, heavy metals, cyanide, volatile organic compounds and semi-volatile organic compounds. Solid wastes were also tested to determine the hazardous waste characteristics of toxicity.

Experimental results

Significantly higher levels of carbon dioxide, carbon monoxide, and total hydrocarbons were measured in the non-sprinklered test than in the sprinklered test. The maximum carbon monoxide levels differed by a factor of 420, while maximum carbon dioxide and total hydrocarbon levels differed by a factor of 24 and 67 respectively. The oxygen concentration in the room decreased to zero in the non-sprinklered room, while the level did not decrease below 18.8% in the sprinklered room.

Air emission results

The 123 species were analyzed for the emission results. There were 76 species detected in either the sprinklered or non-sprinklered case. There were 24 species detected at ratios in excess of 10:1, of which 11 species were detected at ratios in excess of 50:1, and of those six were detected at ratios in excess of 100:1. Four species, NH_3, 1,2,3-trichloropropane, carbon tetrachloride, and o(rtho)-xylene, were detected only in the non-sprinkreled test. Four species, ethanol, hydrogen chloride (HCl), isopropyl alcohol (IPA), and bromoform, were detected only in the sprinkreled test. In general, the results indicated that the total emissions from the sprinkler controlled burn were lower than the emissions from the no sprinkler controlled burn. Below is the list of species and their emission data.

Possibility of flashover

Flashover is defined by the International Standards Organization as “the rapid transition to a state of total surface involvement in a fire of combustible material within an enclosure”. The time to flashover in the non-sprinklered test was determined to be between 271 seconds and 327 seconds. The occurrence of flashover indicated that the fire would have increased the volume of materials consumed by the fire and the quantity of water required to extinguish the fire. Results from the non-sprinklered room indicated that flashover did not occur in this case and the fire was contained within the room.

IMPACT ON GREENHOUSE GASES

According to the calculation done by the FM Global, the use of sprinklers can reduce greenhouse gas emissions by 97.8% in the event of a fire. It was estimated that the total amount of greenhouse gases generated between 1999 and 2008, as a result of residential fires, was 979,950,020 kg.

WATER QUALITY RESULTS

Analytical results indicated that the total copper, zinc, two VOCs (acetone and chloroform), and benzoic acid, a SVOC, were present at a level above the laboratory reporting limits. Acetone, benzene, and chloroform were detected in the sample obtained from the sprinkler controlled burn. Copper, zinc and mercury were detected in dissolved form. Similar types of constituents, such as chloroform, styrene, acetone, and several phenolic compounds, were detected in the samples obtained from the no-sprinkler controlled burn. Heavy metals, including antimony, arsenic, chromium, lead, mercury, and silver, were also detected. Three SVOCs were detected in the no-sprinkler sample, while none was detected in the sprinkler sample, however the reporting limits for SVOCs in the sprinkler sample were similar to or higher than those of the no-sprinkler sample. The sprinkler and no-sprinkler samples contained higher levels of total suspended and dissolved solids, organic carbon, and nutrients (nitrogen and phosphorous). In general, the no sprinkler water samples contained the highest levels of solids and TOC, and a higher pH.

POTENTIAL ENVIRONMENTAL IMPACTS OF WASTEWATER RUNOFF

Fire water runoff carries numerous contaminants and solids that may enter soil, groundwater, or a waterbody and potentially pose a health risk or cause ecological harm. There are numerous examples of large industrial fires where firefighting water runoff resulted in short- and long-term devastating environmental impacts, such as fish kills. Even the small scale fires have the potential to affect the local environment as a result of wastewater runoff:

- Runoff can enter soil, where contaminants in the runoff may absorb onto soil particulates.
- Contaminants bound to soil may eventually leach into groundwater.
- Runoff may directly discharge into a nearby pond, wetland, or stream.
- Runoff can enter a storm water system and eventually discharge into a waterbody.

The pollutant loading to the environmental will be directly influenced by the volume of water generated from firefighting activities and associated wastewater runoff. Thus reducing the volume of fire wastewater would reduce the potential hazard to the environment. The table below shows a comparison of wastewater results to USEPA drinking water standards and guidelines, and to the federal water quality criteria.

FM Global, as part of a two part paper wanted to look at the environmental impact of automatic fire sprinklers, especially in a residential structure. First a method was developed to estimate the lifecycle emissions, including risk factors, was created. One way that the carbon emissions due to fire might present themselves is through a graph where the fire caused an increase in the slope of the graph. It also shows that the impact is felt initially from the fire, but then has long term effects of rebuilding and demolition.

To find a quantifiable method to measure the carbon emissions from the fire and rebuilding the following formulas are used:

$$CE_{fire} = F_b \cdot \dot{m}_f'' \cdot e_{CO_2} \cdot A$$
$$CE_{replacement} = F_r \cdot CE_{embodied}$$

The formulas represent the carbon emissions of the fire by looking at the fraction of material burned, multiplied by the mass of the combustible per area, multiplied by the carbon dioxide released per mass of material, then multiplied by the area of the burning

FM Global experimented on two full scale tests, one living room with a sprinkler and one without. The goal of this research was to examine the relationships between sprinklers and environmental sustainability. Comparisons were made using the total greenhouse gas production, quantity of water used to extinguish the fire, quality of water runoff, the potential impact of the runoff on groundwater, and the mass of materials requiring disposal. The results collected show that sprinklers control a fire much faster than fire department suppression. This paper has very detailed measurements on the amount of greenhouse gases that would result from a residential fire.

The experimental data that was collected during the tests included a qualitative analysis of the water, solid waste analysis on the runoff, temperature, Oxygen, CO_2, CO, particulates, greenhouse gas pollutants, volatile organic compounds. One of the results showed that there was half as much water used in the sprinkler tests (512 gal) than in the non-sprinkler test (1013 gal).

6. ENVIRONMENTAL IMPACT OF WILDFIRE STUDIES

IMPACT OF SMOKE FROM BIOMASS BURNING ON AIR QUALITY IN RURAL COMMUNITIES IN SOUTHERN AUSTRALIA

Source: Reisen, F., Meyer, C. P., McCaw, L., Powell , J. C., Tolhurst, K., Keywood, M. D., & Gras, J. L. (2011). Impact of Smoke from Biomass Burning on Air Quaity in Rural Communities in Southern Australia: Atmospheric Environment. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231011004493

Abstract:
In rural towns of southern Australia, smoke from biomass burning such as prescribed burning of forests, wildfires and stubble burning is often claimed to be the major source of air pollution. To investigate the validity of this claim, ambient measurements of PM2.5 and ozone were made in two rural locations in southern Australia between 2006 and 2008. In order to distinguish PM2.5 associated with smoke from other sources of particulate pollution, PM2.5 samples were analyzed for specific smoke tracers, levoglucosan, non sea-salt potassium (nssKþ) and oxalate. Monitoring clearly showed that, on occasions, air quality in rural areas is significantly affected by smoke from biomass combustion with PM2.5 showing the greatest impact. Concentrations of PM2.5 increased significantly above background levels at both sites during periods of wildfire and prescribed fire leading to exceedances of the 24-h PM2.5 Air National Environment Protection Measure (NEPM) Advisory standard.

Highlights: Air quality monitoring results

Manjimup

Hourly-averaged O3 concentrations ranged from 0.06 ppb to 65 ppb and never exceeded the 1-h NEPM standard of 100 ppb O3 during the sampling period. O3 concentrations show a seasonal cycle with minimum concentrations in summer and maximum concentrations in Winter/Spring. Daily-averaged PM2.5 concentrations ranged from 0.6 ug m-3 to 76.5 ug m-3. The daily NEPM PM2.5 Advisory of 25 ug m-3 was exceeded for 4 days in 2007 and 6 days in 2008. Hourly PM2.5 concentrations ranged from 0.6 ug m-3 to 319 ug m-3, with the maximum concentration measured in November 2007. The sharp increase in hourly PM2.5 and O3 concentrations occurred usually in the afternoon/early evening and lasted between 2 and 11 h. Highest levoglucosan concentrations were measured in August 2007 and May 2008, both episodes of woodheater usage. In contrast, concentrations of nssKþ and oxalate were highest during the spring prescribed burning season.

Oven

The daily PM2.5 NEPM was exceeded on 6 days in April/May 2007 and 6 days in April 2008. Highest concentrations of PM2.5, levoglucosan, nssKþ and oxalate were observed during the autumn prescribed burning season, with oxalate showing an additional peak in summer 2007/2008. Highest pollutant levels were measured during the 2006/2007 wildfires. About 40% of the average hourly PM2.5 concentrations measured between December 12 and January 15 were above 25 ug m-3 and 0.8% exceeded 1 ug m-3. Ovens was clearly impacted by fires and PB, with PM2.5 concentrations being 1.2e5 times higher during the prescribed burning/fire season compared with the non-burning season. During summer 2006/2007, only 15% of daily-measured PM2.5 concentrations were below 10 ug m-3 and 30% exceeded 25 ug m-3, while during autumn 15% of daily-measured PM2.5 concentrations exceeded 25 ug m-3. Daily indoor PM2.5 concentrations exceeded 25 ug m-3 for 2 and 5 days at two of the residences, with maximum daily PM2.5 concentrations measured at 89 ug m-3 and 54 ug m-3.

Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation

Source: Sham, C. H., Tuccillo, M. E., & Rooke, J. (2013). Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation. Washington DC: Environmental Protection Agency. Retrieved from http://www.waterrf.org/Pages/Projects.aspx?PID=4482

This report goes over the effects of the wildfire on drinking water utilities by using a three-stage approach. First they conducted a literature review of the effect of wildfire. Then they conducted a survey to request information from drinking water utilities operators and managers on their experiences. Then they conducted a workshop for different stakeholders from forest service personnel to consultants to water utilities managers.

The literature review focused on three key aspects of assessing and reducing the risk of wildfires, what the effects of wildfire are on water quality and quantity, and what is conducted for post-fire restoration and management.

The majority of effects, from wildfires, on the drinking water utilities, are felt during the post-fire stage. The post fire stage is also measured in years, not weeks or months. The wildfire will have an effect on the nutrients, sulfate, pH, total dissolved solids, turbidity, organic carbon, chloride, iron, color, taste, and odor, which are of concern to the water utilities.

This paper goes over how to quantify the risk/hazard of areas impact on water quality by using a variety of satellite, precipitation, and soil data as well as in-situ data. Using these tools the water utilities are able to reduce the effect that wildfire has on the quality of water.

Long-term Environmental Impact of Catastrophic Forest Fires in Russia's Far East and their Contribution to Global Processes

Source: Yefremov, D. F., & Shvidenko, A. Z. (2004). Long-term Environmental Impact of Catastrophic Forest Fires in Russia'a Far East and their Contribution to Global Processes (Vol. 32): International Forest Fire News. Retrieved from http://www.fire.uni-freiburg.de/iffn/iffn_32/06-Yefremov.pdf

Abstract:
Recent studies have indicated that post-pyrogenic consequences of forest fires, in particular, of catastrophic forest fires, are cumulative in nature. Based on the fire's duration and severity, the level of the fire's concentration over territories, landscapes' and ecosystems' specifics, etc., the transformation of

historically stabilized ecological processes is observed in all ramifications, including both biotic and abiotic spheres, in particular, synoptically processes.

The objectives of this paper are to:

1. Provide a brief characteristic of transformation and long-term environmental consequences of large forest fires and post-pyrogenic disturbances of forest.
2. Assess the global role of regional catastrophic forest fires
3. Describe the trends and rates of ‘green desertification” (deforestation), as well as signs and criteria of pyrogenic impacts on forest ecosystems
4. Consider specific features of fire emissions of greenhouse gases after catastrophic fires

Highlights:
The classification of post fire catastrophic “traumatism” by Sapozhinikov (1984) includes the highest level of a fire’s impacts following destruction of the soil cover, intensive soil erosion, and development of stone fields in mountains. The forests are destroyed completely, and are not restored before new soils are generated. For this class, the loss of potential productive forest land is estimated at more than 80% and lasts for a period of over 20 years.

Long-term pyrogenic consequences are the irreversible transformation of the forest environment, which is obvious beyond the restoration period of an indigenous forest ecosystem, i.e. exceeds the length of the rotation period (i.e., ranging from 100-400 years for major forest forming species of the Russian Far East).

Generally, the long-term environmental consequences of catastrophic forest fires became apparent in the following aspects:

- A significant (up to several times) decrease of the biological productivity of forest lands due to the destruction of the indigenous ecosystem and replacement of indigenous vegetation formations.
- Irreversible changes in the cryogenic regime of soils and rocks.
- Change of long-term amplitude of hydrothermal indicators beyond natural fluctuations.
- Changes of multi-year average hydrothermal and bio-chemical indicators of aquatic and sediment runoff, as well as of hydrological regimes and channel processes of water streams.
- Accumulative impacts on atmospheric processes resulting in global climate change.
- Acceleration of large scale outbreaks of insects and disease.
- Irreversible loss of biodiversity including rare and threatened flora and fauna species.
- Transboundary water and air transfer of pyrogenic products.
- Change of historical migration routes for migratory birds, ground and water animals.

WILDLAND FIRE IN ECOSYSTEMS: EFFECTS OF FIRE ON AIR

Source: Sandberg, D. V., Ottmar, R. D., Peterson, J. L., & Core, J. (2002). Wildland Fire in Ecosystems: Effects of Fire on Air (Vol. RMRS-GTR-42). Washington DC: United States Department of Agriculture. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_gtr042_5.pdf

Extremely comprehensive document that contains information on air pollution from fires, how to characterize emissions from fires, plume chemistry, how to estimate the quality impacts of fire, the consequences of fire on air quality.

WILDFIRE: A BURNING ISSUE FOR INSURERS?

Source: Doerr, S., & Santin, C. (2013). Wildfire: A Burning Issue for Insurers? : Lloyd's. Retrieved from http://www.lloyds.com/~/media/lloyds/reports/emerging%20risk%20reports/wildfire%20final.pdf

Wildfires are going to pose a significant and increasing risk to lives and property in the coming year. Changes in socioeconomic grouping and land use has raised the risk of severe fires by allowing for the existing fuel load to grow beyond naturally occurring levels. The risk is expected to grow in the western and southern part of the US, south-west Canada, parts of the Mediterranean basin, eastern Siberia, south-central Australia, western South America and much of the drier regions in Asia. Wildland fires affect three to four million square kilometers (3% of the earth vegetated land surface) every year. Over 80% of the global area burned occurs in grassland and savannahs in Africa and Australia, however due to their frequency they rarely cause human or economic losses.

INFLUENCE OF FOREST FIRES ON CLIMATE CHANGE STUDIES IN THE CENTRAL BOREAL FOREST OF CANADA

Source: Valeo, C., Beaty, K., & Hesslein, R. (2003). Influence of Forest Fires on Climate Change Studies in the Central Boreal Forest of Canada. *Journal of Hydrology*, *280*, 91-104. Retrieved from http://www.sciencedirect.com/science/article/pii/S0022169403001859

Study looking at whether a watershed region that experienced forest fires had any effect on the total runoff. The result seemed to be that after a forest fire there was less runoff into the watershed area, possibly because of increased evapotranspiration of newer vegetation.

7. TECHNIQUES FOR ANALYSIS

ENVIRONMENTAL ASSESSMENT OF FIRES IN PRODUCTS USING THE FIRE-LCA MODEL

Source: Simonson, M., Andersson, P., Blomqvist, P., & Stripple, H. (2005). Environmental Assessment of Fires in Products Using the Fire-LCA Model. *Fire Safety Science - Proceedings of 8th International Symposium*, 1071-1082. Retrieved from http://www.iafss.org/publications/fss/8/1071/view

The Fire-LCA offers several improvements over a typical LCA. The Fire-LCA is a comparative study between whether a product ends up in a fire or not. Problems with this method is the amount of input data needed and the emission data available. Additionally it was found that controlling the ignitibility and growth of fire in products, resulted in a major reduction on toxic environmental pollutants, such as PAH. In contrast species like CO only result in minor differences. Flame retardants present significant differences in the Fire-LCA.

LIFE-CYCLE ASSESSMENT INCLUDING FIRES (FIRE-LCA)

Source: Andersson, P., Simonson, M., & Stripple, H. (2007). Life-Cycle Assessment Including Fires (Fire-LCA). Retrieved from http://link.springer.com/chapter/10.1007/978-3-540-71920-5_11

This is a chapter in a book based on explaining how to perform a "Fire-LCA". The Fire-LCA takes into account how a fire might impact the life cycle cost of a product because of this is accounts for any fire protection measures as a benefit. The chapter describes the process and resources for conducting a typical LCA. The LCA includes an impact assessment of the product, which can be controversial because of the lack of standardization.

AN ENVIRONMENTAL IMPACT AND COST BENEFIT ANALYSIS OF FIRE SPRINKLERS IN WAREHOUSE BUILDINGS

Source: Fraser-Mitchell, D. J., Abbe, D. O., & Williams, D. C. (2013). An Environmental Impact and Cost Benefit Analysis for Fire Sprinklers in Warehouse Buildings (Vol. 271836 rev2). Watford, Herts: BRE Global.

The number of fires is decreasing, while the cost of fires to commercial warehouses is increasing. The BRE study looked at warehouses of 3 different sizes and compared the effects of having sprinklers and not having sprinklers. To main goal of the study was to determine whether it is cost-effective to install and maintain sprinklers in a warehouse. The cost-effectiveness is evaluated using a life cycle analysis. The main tenants of the analysis are the economic costs, social costs, and environmental costs. The environmental costs are broken down into CO_2 emissions, water used in fire fighting, production of building waste, and resources needed for rebuild. The study revealed that warehouses with an area of 10,000 m^2 or larger, results in a 2.2-5.3 times smaller life cycle cost than the same building without sprinklers. To estimate the amount of CO_2 involved the contents of the building were modeled as FM Global standard pallets, and the volume of those contents are tallied. A monte-carlo analysis is used to realize the total number of pallets burned in the fire.

The purpose for this report was that despite the decreasing number of fires the cost of fire is still increasing for the warehouses in England. The study carried out an environmental assessment for an "exemplar warehouse" as a cradle to site life cycle assessment. The consequences that were considered were:

- Area of fire damage; Area of smoke damage
- Number of fatalities and injuries
- CO2 released by burning
- Quantity of water used for fire fighting
- Probability that the building will need to be demolished and rebuilt
- CO2 embodied in replacement of building
- Number of people unemployed following the fire and for what duration

Overall Conclusion
The cost of a warehouse fire when sprinklers are installed is generally much lower when there is a fire

Cost Benefit Analysis Methodology
The cost benefit methodology is very clearly laid out in the literature. The factors which presented the highest uncertainty underwent a Monte Carlo analysis to account for the uncertainty of each individual factors. They assumed 6 building types from small to large warehouses, with or without sprinklers. The analysis considered the "Whole Life Costs" of a building. This took into account such things as the buildings area, to the annual maintenance of the system to the frequency and impact of a fire. The impacts such as the size and impact of the smoke were taken into account as well as the injuries/casualties, and whether the building needed to be demolished.

Environmental impacts of fires and sprinklers in warehouses

The environmental impact of fire has been done using two metrics one metric is using tons of CO_2 and the other is using ecopoints. Where ecopoints are normalized so that the annual environmental impact of an average person is 100 ecopoints. The data points that are used to make up that metric are as follows:

- Acidification
- Photochemical Ozone Creation
- Eutrophication
- Fossil Fuel Depletion
- Waste Disposal
- Exotoxicity to land
- Nuclear Waste
- Exotoxicity to Freshwater
- Human Toxicity
- Stratospheric Ozone Depletion
- Mineral Resource Extraction
- Water Extraction
- Climate Change

For this study the group did not look at the life cycle cost of the building. First they looked at the environmental impact associated with the building, then the racks in that building, and then the sprinkler system.

This environmental impact assessment in this case focused on the costs associated with building the building and the sprinkler system and the contents, but not the actual fire incidence. Included in this is the study of solid emission resulting from the fire incident. Additionally, BRE would like sufficient data to complete their “Environmental Profiles Methodology”.

The next realization for the environmental impact assessment was to give a comparative estimate between the impact of a fire in a building with sprinklers versus one without a sprinkler system. Including an estimate of the impact of burning materials, replacing contents, rebuilding, and water usage.

APPENDIX D: BIBLIOGRAPHY OF RELEVANT LITERATURE

Ahrens, M. (2013). Brush, Grass, and Forest Fires (Vol. USS89). Quincy, MA: National Fire Protection Association. Retrieved from http://www.nfpa.org/~/media/C4BFD30DCD6344E397650B189686F96E.ashx

Air Risk Information Support Center. (1993). Toxic Emissions From Aircraft Firefighting Training (Vol. 453-R-93-027). Research Triangle Park, NC: Environmental Criteria and Assessment Office. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000HJMX.txt

Allen, C. D. (2010). A Global Overview of Drought and Heat-Induced Tree Mortality Reveals Emerging Climate Change Risks for Forests. *Forest Ecology and Management, 259*, 660-684. Retrieved from http://www.sciencedirect.com/science/article/pii/S037811270900615X

Alqassim, Mohammad A., & Daeid, N. N. (2014). Fires and Related Incidents in Dubai, United Arab Emirates (2006-2013): Case Studies in Fire Safety. Retrieved from http://www.sciencedirect.com/science/article/pii/S2214398X14000089 http://ac.els-cdn.com/S2214398X14000089/1-s2.0-S2214398X14000089-main.pdf?_tid=62af2330-99ac-11e4-be48-00000aab0f6b&acdnat=1420992819_ad9db6abad24bbf9175fc3b7ce7b4014

Andersson, P., Simonson, M., & Stripple, H. (2007). Life-Cycle Assessment Including Fires (Fire-LCA). Retrieved from http://link.springer.com/chapter/10.1007/978-3-540-71920-5_11

Arvai, J. L. (2003). Human and Ecological Risk Assessment: Theory and Practice. *Journal of Environmental Education, 34*, 39+. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE%7CA113304384&v=2.1&u=mlin_c_worpoly&it=r&p=GRGM&sw=w&asid=dea44ceac7e8aa0261af32deca53a73c

Badger, S. G. (2014). Large-Loss Fires in the United States 2013 (Vol. LLS10). Quincy, MA: National Fire Protection Association. Retrieved from http://www.nfpa.org/~/media/4A15D43A99244553B129C7FD7A25AB66.ashx

Bare, J. C., Haes, H. A. U. d., & Pennington, D. W. (2000). An Internal Workshop on Life Cycle Impact Assessment Sophistication (Vol. EPA-600\R-00-023). Cincinnati, OH: Evironmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=30002DWK.txt

Barnett, J., & Stratton, B. (2014, 2014). *Sustainability Challenges in Fire Safety Engineering.* Paper presented at the Practical Responses to Climate Change.

Bhuptani, P., Strauss, J., & Vaillancourt, A. (2005). Environmental Assessment of Chemical Incidents (WPI IQP) (Vol. E-project-070805-123703). Worcester, MA: IQP Worcester Polytechnic Institute. Retrieved from https://www.wpi.edu/Pubs/E-project/Available/E-project-070805-123703/unrestricted/BomberosE05.pdf

Blais, M., & Carpenter, K. (2013). Flexible Polyurethane Foams: A Comparative Measurement of Toxic Vapors and Other Toxic Emissions in Controlled Combustion Evironments of Foams With and Without Fire Retardants. *Fire Technology, 51*, 3-18. doi: 10.1007/s10694-013-0354-5. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-013-0354-5

Blais, M., & Carpenter, K. (2014). Combustion Characteristics of Flat Panel Televisions With and Without Fire Retardants in the Casing. *Fire Technology, 51*, 19-40. doi: 10.1007/s10694-014-0420-7. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-014-0420-7

Blomqvist, P. (2005). *Emissions from Fires: Consequences for Human Safety and the Environment.* (Fire Safety Engineering Doctoral), Lund University, Lund University. Retrieved from http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=545459&fileOId=545460 Retrieved from http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=545459&fileOId=545460

British Standards Institution Group. (2001). Draft BS 7982: Guidence on Environmental Impact of Large-Scale Fires involving Plastics Materials. Retrieved from http://www.frocc.org/pdf/regulation/BS_7982.pdf

Brnich Jr, M. J., & Kowalski-Trakofker, K. M. (2010). Underground Coal Mine Disasters 1900 - 2010:

Events, Responses, and a Look to the Future. Retrieved from http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/ucmdn.pdf

Brushlinsky, N. N., Ahrens, M., Sokolov, S. V., & Wagner, P. (2013). Center of Fire Statistics: World Fire Statistics. Retrieved from http://www.ctif.org/sites/default/files/ctif_report19_world_fire_statistics_2014.pdf

Canter, L. W. (1999). Environmental Impact Assessment. In H. F. L. Ed. David & G. L. Bela (Eds.), *Environmental Engineer's Handbook*. Boca Raton: CRC Press LLC. Retrieved from http://www.crcnetbase.com/doi/pdfplus/10.1201/NOE0849321573.ch2

Carvalho, A., Monteiro, A., Flannigan, M., Solman, S., Miranda, A. I., & Borrego, C. (2011). Forest Fires in a Changing Climate and their Impacts on Air Quality. *Atmospheric Environment, 45*, 5545-5553. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231011004821

Chettouh, S., Hamzi, R., Innal, F., & Haddad, D. (2013, 2013). *Uncertainty in the Dynamic LCA - Fire methodology to assess the environmental fire effects 3th IEEE International Conference on Systems and Control, ICSC 2013.* Paper presented at the Systems and Control (ICSC), 2013 3rd International Conference on. Retrieved from http://ieeexplore.ieee.org/ielx7/6746884/6750820/06750852.pdf?tp=&arnumber=6750852&isnumber=6750820

Clinton, N. E., Gong, P., & Scott, K. (2006). Quantification of Pollutants Emitted from Very Large Wildland Fires in Southern California, USA. 3686-3695. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231006002135

Covello, V. T. (1993). *Risk assessment methods : approaches for assessing health and environmental risks*. New York: Plenum Press. Retrieved from http://books.google.com/books/about/Risk_Assessment_Methods.html?id=mglNQLEQsIwC

Crouch, R. L., Timmenga, H. J., Barber, T. R., & Fuchsman, P. C. (2006). Post-fire surface water quality: Comparison of fire retardant versus wildfire-related effects. *Chemosphere, 62*, 874-889. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653505007435

Doerr, S., & Santin, C. (2013). Wildfire: A Burning Issue for Insurers? : Lloyd's. Retrieved from http://www.lloyds.com/~/media/lloyds/reports/emerging%20risk%20reports/wildfire%20final.pdf

Eastern Research Group. (2013). Recommended Procedures for Development of Emissions Factors and Use of the WebFIRE Database (Vol. EPA-453/D-13-001). Research Triangle Park, NC: Evironmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100GQWC.txt

Environmental Protection Agency. (1991). Kuwait Oil Fires: Interagency Interim Report. Washington, DC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=90050O00.txt

Environmental Protection Agency. (1992). Environmental Impact Assessments (Vol. EPA-600/M-91/037). Washington DC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=300024Q1.txt

Environmental Protection Agency. (1993). Analysis of Ambient Monitoring Data in the Vicinity of Open Tire Fires (Vol. EPA-453/R-93-029). Research Triangle Park, NC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000HJQT.txt

Environmental Protection Agency. (1995). FIRE Version 5.0: Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants (Vol. EPA-454/R-95-012). Research Triangle Park, NC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=00003591.txt

Environmental Protection Agency. (1998). *Guidelines for Ecological Risk Assessment*. (EPA/630/R-95/002F). Retrieved from http://www.epa.gov/raf/publications/pdfs/ECOTXTBX.PDF.

Environmental Protection Agency. (2000). Carbon Dioxide as a Fire Suppressant: Examining the Risks (Vol. EPA430-R-00-002). Washington DC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=00000NTO.txt

Environmental Protection Agency. (2002). National Recommended Water Quality Criter: Human Health

Criter Calculation Matrix. Retrieved from http://water.epa.gov/scitech/swguidance/standards/upload/2002_12_30_criteria_wqctable_hh_calc_matrix.pdf

Environmental Protection Agency. (2010). *Environmental Crisis in the Gulf: The U.S. Response*. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100K6UO.txt.

Environmental Protection Agency (2014). [Environmental Assessments & Environmental Impact Statements]. Web Page.

Federal Emergency Management Agency (2014). [Environmental Impact Statements]. Web Page.

Federal Register. (2010). Nationwide Aerial Application of Fire Retardant on National Forest System Lands. *Federal register*. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE%7CA235682797&v=2.1&u=mlin_c_worpoly&it=r&p=AONE&sw=w&asid=e36660133cfa0e22a59a64e6418fb06b

Federal Register. (2013). Hazardous Fire Risk Reduction, East Bay Hills, CA. *Federal register*. Retrieved from http://go.galegroup.com/ps/i.do?id=GALE%7CA329942135&v=2.1&u=mlin_c_worpoly&it=r&p=AONE&sw=w&asid=5726c51f31f61f56179d6aee55189c14

Fitzgerald, G., & Fitzgerald, N. (2005). Assessing Community Resilience to Wildfires: Concepts & Approach: Scion Research. Retrieved from http://www.tba.co.nz/tba-eq/Assessing_community_resilience_to_wildfires_-_fitzgerald_2005.pdf

Flannigan, M. D., Stocks, B. J., & Wotton, B. M. (2000). Climate Change and Forest Fires. *The Science of the Total Environment*, 221-229. Retrieved from http://www.sciencedirect.com/science/article/pii/S0048969700005246

Food and Agriculture Organization of the United Nations. (2013). Climate Change Guidelines for Forest Managers. Retrieved from http://www.fao.org/docrep/018/i3383e/i3383e.pdf

Forti, M., LeBlanc, M., & McManus, K. (2013). Reducing the Environmental Impact of Hazardous Wastes in the Fire Protection Industry of Australia (WPI IQP) (Vol. 41-MJA-F001 [E-project-042913-202327]). Worcester, MA: WPI. Retrieved from http://www.wpi.edu/Pubs/E-project/Available/E-project-042913-202327/unrestricted/FPA_Final_Report.pdf

Fraser-Mitchell, D. J., Abbe, D. O., & Williams, D. C. (2013). An Environmental Impact and Cost Benefit Analysis for Fire Sprinklers in Warehouse Buildings (Vol. 271836 rev2). Watford, Herts: BRE Global.

Fufa, S. M., Jelle, B. P., & Hovde, P. J. (2014). Wood Material Science & Engineering. Retrieved from http://dx.doi.org/10.1080/17480272.2013.803500

Gomez-Rey, M. X., & Gonzalez-Preto, S. J. (2014). Short and medium-term effects of a wildfire and two emergency stabilization treatments on the availability of macronutrients and trace elements in topsoil. *Science of the Total Environment, 493,* 251-261. Retrieved from http://www.sciencedirect.com/science/article/pii/S0048969714008110#

http://ac.els-cdn.com/S0048969714008110/1-s2.0-S0048969714008110-main.pdf?_tid=59bb012c-99ac-11e4-adcf-00000aab0f02&acdnat=1420992804_2d06465e7e7a7bdaf5223a08f05220da

Gritzo, L. A., Bill Jr, R. G., Wieczorek, C. J., & Ditch, B. (2011). Environmental Impact of Automatic Fire Sprinklers: Part 1. Residential Sprinklers Revisited in the Age of Sustainability. - *Fire Technology, 47*(3), 751-763. doi: 10.1007/s10694-010-0191-8. Retrieved from - http://dx.doi.org/10.1007/s10694-010-0192-7

http://link.springer.com/article/10.1007%2Fs10694-010-0192-7#

http://download.springer.com/static/pdf/742/art%253A10.1007%252Fs10694-010-0191-8.pdf?auth66=1420992652_b71727fe810561bb9c7e63d8a4f9b305&ext=.pdf

Gritzo, L. A., Doerr, W., Bill, R., Ali, H., Nong, S., & Krasner, L. (2009). The Influence of Risk Factors on Sustainable Development. Norwood, MA: FM Global Research Division. Retrieved from http://www.fmglobal.com/assets/pdf/P09104a.pdf

Hamzi, R., & Innal, F. (2011, 2011). *A Quantitative Risk Assessment Approach for the Dynamic Environmental Impact of Fire.* Paper presented at the Management and Service Science (MASS),

2011 International Conference on. Retrieved from http://ieeexplore.ieee.org/ielx5/5996071/5997898/05999345.pdf?tp=&arnumber=5999345&isnumber=5997898
Hamzi, R., Innal, F., Bourmada, N., & Londiche, H. (2009). An Environmental Analysis of the Impact of an Accidential Fire in Process Industries. *International Journal of Chemical Reactor Engineering, 7*(A88). Retrieved from http://hal-emse.ccsd.cnrs.fr/emse-00450147
Hamzi, R., Londiche, H., & Bourmada, N. (2008). Fire-LCA model for environmental decision-making. *Chemical Engineering Research and Design, 86*(10), 1161-1166. doi: http://dx.doi.org/10.1016/j.cherd.2008.05.004. Retrieved from http://www.sciencedirect.com/science/article/pii/S0263876208001433
http://ac.els-cdn.com/S0263876208001433/1-s2.0-S0263876208001433-main.pdf?_tid=5caf03ec-99ac-11e4-a816-00000aacb360&acdnat=1420992809_e88f69335d62aa8c7ceb8952f003a766
Hand, M. S., Wibbenmeyer, M. J., Calkin, D. E., & Thompson, M. P. (2014). Risk Preferences, Inefficiencies, and Opportunities in Wildfire Management. Retrieved from http://cdn1.sph.harvard.edu/wp-content/uploads/sites/1273/2014/02/Risk-Perception-Hand-et-al.pdf
Harbridge House I. N. C. (1976). Socioeconomic Impact Assessment of Proposed Air Quality Attainment and Maintenance Strategies (Vol. EPA-901/9-76-003). Boston, MA: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100UVCJ.txt
Hardy, C. C. (2005). Wildland Fire Hazard and Risk: Problems, Definitions, and Context. *Forest Ecology and Management, 211*, 73-82. Retrieved from http://www.sciencedirect.com/science/article/pii/S037811270500040X
Health and Safety Executive. (1993). Case studies illustrating the importance of Emergency response / spill control. Retrieved January 26, 2015, from http://www.hse.gov.uk/comah/sragtech/techmeasspill.htm
Health and Safety Executive. (1993). The fire at Allied Colloids Limited. A report of the HSE's investigation into the fire at Allied Colloids Ltd, Low Moor, Bradford on 21 July 1992. Retrieved from http://www.icheme.org/communities/special-interest-groups/safety%20and%20loss%20prevention/resources/~/media/D3C58AAE7B7D4BF392E3885D728AAC0E.pdf
Heitmann, K., Wichmann, H., Bahadir, M., Gunschera, J., Schulz, N., & Salthammer, T. (2011). Chemical composition of burnt smell caused by accidental fires: Environmental contaminants. *Chemosphere, 82*, 237-243. doi: 10.1016/j.chemosphere.2010.09.065. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653510010921#
Holemann, H. (1994). Environmental Problems Caused by Fires and Fire-Fighting Agents. *Fire Safety Science - Proceedings of 4th International Symposium*, 61-77. Retrieved from http://www.iafss.org/publications/fss/4/61/view
Howard, G. J. (2014). Chemical alternatives assessment: The case of flame retardants. *Chemosphere, 116*, 112-117. doi: 10.1016/j.chemosphere.2014.02.034. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653514002380
Huie, R. E. (2003). Environmental Impact of New Chemical Agents for Fire Suppression. Gaithersburn, MD: The Department of Defense Strategic Environmental Research and Development Program. Retrieved from http://www.dtic.mil/dtic/tr/fulltext/u2/a418320.pdf
International Organization for Standardization. (2011). ISO/CD 26367-2 Guidelines for assessing the adverse environmental impact of fire effluents -- Part 2: Compilation of environmentally significant emissions from fires. Retrieved from http://www.iso.org/iso/catalogue_detail.htm?csnumber=50635
International Organization for Standardization. (2012). ISO/TR 26361:2012・Environmental damage limitation from fire-fighting water run-off. Retrieved from http://www.iso.org/iso/catalogue_detail.htm?csnumber=43530
Karter Jr, M. J. (2014). Fire Loss in the United States During 2013 (Vol. FLX10-01). Quincy, MA:

National Fire Protection Association. Retrieved from http://www.nfpa.org/~/media/FD0144A044C84FC5BAF90C05C04890B7.ashx
Kenward, A., Adams-Smith, D., & Raja, U. (2013). Wildfires and Air Pollution: The Hidden Health Hazards of Climate Change. Retrieved from http://assets.climatecentral.org/pdfs/WildfiresAndAirPollution.pdf
Kerber, S. (2012). Analysis of Changing Residential Fire Dynamics and Its Implications on Firefighter Operational Timeframes: Underwriters Laboratories. Retrieved from http://newscience.ul.com/wp-content/uploads/sites/30/2014/04/Analysis_of_Changing_Residential_Fire_Dynamics_and_Its_Implications_on_Firefighter_Operational_Timeframes.pdf
Kuenzer, C., Zhang, J., Tetzlaff, A., van Dijk, P., Voigt, S., Mehl, H., & Wagner, W. (2007). Uncontrolled Coal Fires and Their Environmental Impacts: Investigating Two Arid Mining Regions in North-central China: Applied Geography. Retrieved from http://www.sciencedirect.com/science/article/pii/S0143622806000142
http://ac.els-cdn.com/S0143622806000142/1-s2.0-S0143622806000142-main.pdf?_tid=5ee4a220-99ac-11e4-8e66-00000aab0f01&acdnat=1420992813_a9848f7cd3fbcc3c4a0e7c3c37850713
Langmann, B., Duncan, B., Textor, C., Trentmannd , J., & van der Werf, G. R. (2008). Vegetation Fire Emissions and Their Impact on Air Pollution and Climate: Atmospheric Environment. Retrieved from http://www.sciencedirect.com/science/article/pii/S135223100800900X
http://ac.els-cdn.com/S135223100800900X/1-s2.0-S135223100800900X-main.pdf?_tid=507ab882-99ac-11e4-b9ef-00000aacb35f&acdnat=1420992789_b6ed4983fd0b817e261cf2f3b0359513
Llompart, M., Sanchez-Prado, L., Lamas, J. P., Garcia-Jares, C., Roca, E., & Dagnac, T. (2013). Hazardous organic chemicals in rubber recycled tire playgrounds and pavers. doi: 10.1016/j.chemosphere.2012.07.053. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653512009848
Lonnermark, A., Blomqvist, P., & Marklund, S. (2008). Emissions from simulated deep-seated fires in domestic waste. *Chemosphere, 70*, 626-639. doi: 10.1016/j.chemosphere.2007.06.083. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653507008636
Marlair, G., Simonson, M., & Gann, R. G. (2004). Environmental Concerns of Fires: Facts Figures, Questions, and New Challenges for the Future. *Interflam*, *1*, 325-337. Retrieved from http://fire.nist.gov/bfrlpubs/fire04/PDF/f04038.pdf
McNamee, M. S. (2014). Guest Editorial: Fire and the Environment. *Fire Technology, 51*(1), 1-2. doi: 10.1007/s10694-014-0444-z. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-014-0444-z
McNamee, M. S., & Andersson, P. (2014). Application of a Cost–benefit Analysis Model to the Use of Flame Retardants. *Fire Technology, 51*, 67-83. doi: 10.1007/s10694-014-0402-9. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-014-0402-9
Melamed, L., Eden, E., Leifer, M., & Georlette, P. (2014). Performances of Blends Between Poly(pentabromobenzyl acrylate) and Magnesium Hydroxide as Flame Retardants for Polypropylene Block Copolymers. *Fire Technology, 51*, 41-52. doi: 10.1007/s10694-014-0404-7. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-014-0404-7
Miles, S. D., Cox, G., Christolis, M. N., Christidou, C. A., Boudouvis, A. G., & Markatos, N. C. (1994). Modelling the Environmental Consequences of Fires in Warehouses. *Fire Safety Science - Proceedings of 4th International Symposium*, 1221-1232. Retrieved from http://www.iafss.org/publications/fss/4/1221/view
Modovsky, C. (2007). Ecological Risk Assessment: Wildland Fire-Fighting Chemicals. Missoula, MT: USDA Forest Service. Retrieved from http://www.fs.fed.us/rm/fire/wfcs/documents/era_pub.pdf
Moe, M. K., Huber, S., Svenson, J., Hagenaars, A., Pabon, M., Trümper, M.,... Herzke, D. (2012). The structure of the fire fighting foam surfactant Forafac 1157 and its biological and photolytic transformation products. *Chemosphere, 89*, 869-875. doi: dx.doi.org/10.1016/j.chemosphere.2012.05.012. Retrieved from

http://www.sciencedirect.com/science/article/pii/S0045653512006091
Moore, S., Burns, B., O'Halloran, K., & Booth, L. (2007). Impact of Fire Service Activity on the Environment (Vol. LC0607/098). Wellington, New Zealand: Landcare Research. Retrieved from http://www.fire.org.nz/Research/Published-Reports/Documents/5b4467e712133823ca35d26c80e6386e.pdf
Morton, D. C., Roessing, M. E., Camp, A. E., & Tyrrell, M. L. (2003). Assessing the Environmental, Social, and Economic Impacts of Wildfire (Vol. GISF - 001). New Haven, CT: Yale University. Retrieved from http://environment.yale.edu/gisf/files/pdfs/wildfire_report.pdf
Moussa, N. A., & Devarakonda, V. V. (2014). Prediction of Toxic Emissions from Chemical Fire and Explosion: International Association for Fire Safety Science. Retrieved from http://www.iafss.org/publications/fss/11/205/view
Munchak, L. A., Schichtel, B. A., Sullivan, A. P., Holden, A. S., Kreidenweis, S. M., Malm, W. C., & Collett, J. L. (2011). Development of Wildland Fire Particulate Smoke Marker to Organic Carbon Emission Ratios for the Conterminous United States. *Atmospheric Environment*. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231010008678
Murray, V., & Goodfellow, F. (2002). Mass Casualty Chemical Incidents - Towards Guidance for Public Health Management. *Public Health, 116*(1), 2-14. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11896630
http://www.sciencedirect.com/science/article/pii/S0033350602900533
National Aeronautics & Space Administration. (1991). Smoke plumes from the Kuwaiti Oil Fires. In STS037-152-91 (Ed.). Retrieved from http://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=STS037&roll=152&frame=91
National Interagency Coordination Center. (2003). 1997-2013 large fires (100,000+ acres).
National Interagency Coordination Center. (2013). Wildland Fire Summary and Statistics Annual Report 2013 - Resource Statistics. Retrieved from http://www.predictiveservices.nifc.gov/intelligence/2013_Statssumm/resource_charts_tables13.pdf
National Interagency Coordination Center. (2013). Wildland fires and acres (1960-2013). Retrieved from http://www.nifc.gov/fireInfo/fireInfo_stats_totalFires.html
National Park Service. (1999). Redwood National and State Parks, Humboldt and Del Norte Counties, California. Sacramento: National Park Service. Retrieved from http://babel.hathitrust.org/cgi/pt?id=mdp.39015052393744;view=1up;seq=1
National Park Service. (2012). Yellowstone National Park Wildland Fire Management Plan: Environmental Assessment. Yellowstone National Park, WY: Yellowstone National Park Service. Retrieved from http://www.nps.gov/yell/parkmgmt/wildland-fire-program.htm
Nelson, G. L. (2000). Fire and Pesticides, A Review and Analysis of Recent Work. *Fire Technology, 36*(3), 163-183. Retrieved from http://link.springer.com/article/10.1023/A%3A1015462710856
New Zealand Fire Service. (2001). The Ecotoxic Effects of Fire-Water Runoff, Part III: Proposed Framework for Risk Management. In J. Fowles (Ed.), *The Ecotoxic Effects of Fire-Water Runoff,* : New Zealand Fire Service. Retrieved from http://www.fire.org.nz/Research/Published-Reports/Documents/06d15a58fd0db2bf6e739492a8ac6337.pdf
New Zealand Fire Service. (2001). The Ecotoxic Effects of Fire-Water Runoff: Part I: Literature Review. *The Ecotoxic Effects of Fire-Water Runoff.* from http://www.fire.org.nz/Research/Published-Reports/Documents/2a6e4acb13e45a94afef2c9550adbd24.pdf
New Zealand Fire Service. (2001). The Ecotoxic Effects of Fire-Water Runoff: Part II: Analytical Results *The Ecotoxic Effects of Fire-Water Runoff*. Retrieved from http://www.fire.org.nz/Research/Published-Reports/Documents/f38e4c51bada29d5242fc79515278a1f.pdf
Nikolaeva, M., & Karki, T. (2013). Reaction-to-Fire Properties of Wood–Polypropylene Composites Containing Different Fire Retardants. *Fire Technology, 51*, 53-65. doi: 10.1007/s10694-013-0377-y. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-013-0377-y

Nolter, M. A., & Vice, D. H. (2004). Looking back at the Centralia coal fire: a synopsis of its present status. *International Journal of Coal Geology*, *59*(1-2), 99-106. doi: 10.1016/j.coal.2003.12.008. Retrieved from http://www.sciencedirect.com/science/article/pii/S0166516204000187

Padelford, K., & Whipple, C. (2011). A Systems Engineering Approach to Green Home Design: The Need to Incorporate Residential Fire Sprinklers (WPI IQP) (Vol. E-project-053111-122914). Worcester, MA: WPI. Retrieved from https://www.wpi.edu/Pubs/E-project/Available/E-project-053111-122914/unrestricted/Sprinkler_IQP_Draft_10.pdf

Pennsylvania Department of Environmental Protection. (2013). The Centralia Mine Fire Frequently Asked Questions/Answers. from http://files.dep.state.pa.us/Mining/Abandoned%20Mine%20Reclamation/AbandonedMinePortalFiles/Centralia/CentraliaFrequentlyAskedQuestions.pdf#nameddest=B

Pietrovito, J., Carney, S., & Magder, A. (2002). Minimising the Potential Impact of Structural Fire-Fighting on Water Quality.

Reisen, F., Meyer, C. P., McCaw, L., Powell , J. C., Tolhurst, K., Keywood, M. D., & Gras, J. L. (2011). Impact of Smoke from Biomass Burning on Air Quaity in Rural Communities in Southern Australia: Atmospheric Environment. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231011004493

http://ac.els-cdn.com/S1352231011004493/1-s2.0-S1352231011004493-main.pdf?_tid=5524de9e-99ac-11e4-b1e6-00000aab0f01&acdnat=1420992797_d86711355caf81075b980fdc0192f43b

Robbins, A. P. (2012). Building Sustainability and Fire-Safety Design Interactions: Scoping Study. Retrieved from http://www.branz.co.nz/cms_show_download.php?id=716733515027fe4626188881f674635d51e3cfb0

Robbins, A. P., Page, I. C., & Jaques, R. A. (2010). House Fire GHG Emissions Estimation Tool (Vol. SR 217). New Zealand: BRANZ. Retrieved from http://www.branz.co.nz/cms_show_download.php?id=c39553fa6b631c9c4c3521d528dd40489d8ceef4

Routley, J. G. (1989). Conservative Approach to Chemical Plant Fire: U.S. Fire Administration. Retrieved from http://www.usfa.fema.gov/downloads/pdf/publications/tr-029.pdf

Sakai, S.-i., Deguchi, S., Takatsuki, H., & Uchibo, A. (2001). Large-scale fires and time trends of PCDDs/DFs in sediments. *Chemosphere*, *43*, 537-547. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653500004057

Sandberg, D. V., Ottmar, R. D., Peterson, J. L., & Core, J. (2002). Wildland Fire in Ecosystems: Effects of Fire on Air (Vol. RMRS-GTR-42). Washington DC: United States Department of Agriculture. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_gtr042_5.pdf

Sham, C. H., Tuccillo, M. E., & Rooke, J. (2013). Effects of Wildfire on Drinking Water Utilities and Best Practices for Wildfire Risk Reduction and Mitigation. Washington DC: Environmental Protection Agency. Retrieved from http://www.waterrf.org/Pages/Projects.aspx?PID=4482

Shiea, R.-H., & Chana, C.-C. (2013). Tracking Hazardous Air Pollutants from a Refinery Fire by Applying On-line and Off-line Air Morning and Back Trajectory Modeling: J Hazard Mater. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23912073

Simonson, M., Andersson, P., Blomqvist, P., & Stripple, H. (2005). Environmental Assessment of Fires in Products Using the Fire-LCA Model. *Fire Safety Science - Proceedings of 8th International Symposium*, 1071-1082. Retrieved from http://www.iafss.org/publications/fss/8/1071/view

Snowden, W. D., Alguard, D. A., Swanson, G. A., & Stolberg, W. E. (1975). Source Sampling Residential Fire Places for Emission Factor Development (Vol. EPA-450/3-76-010). Research Triangle Park, NC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=910105Q2.txt

Sommers, W. T., Loehman, R. A., & Hardy, C. C. (2014). Wildland Fire Emissions, Carbon, and Climate: Science Overview and Knowledge needs. *Forest Ecology and Management*, *317*, 1-8. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378112713008165#

Stec, A. A., Readman, J., Blomqvist, P., Gylestam, D., Karlsson, D., Wojtalewicz, D., & Dlugogorski, B. Z. (2013). Analysis of toxic effluents released from PVC carpet under different fire conditions. *Chemosphere, 90*, 65-71. doi: 10.1016/j.chemosphere.2012.07.037. Retrieved from http://dx.doi.org/10.1016/j.chemosphere.2012.07.037

Stein, S. M., Comas, S. J., Menakis, J. P., Carr, M. A., Stewart, S. I., Cleveland, H.,... Radeloff, V. C. (2013). Wildfire, Wildlands, and People: Understanding and Preparing for Wildfire in the Wildland-Urban Interface (Vol. RMRS-GTR-299): United States Department of Agriculture. Retrieved from http://www.fs.fed.us/openspace/fote/wildfire-report.html

Sweis, F. K. (2006). Fires and Related Incidents in Jordan (1996-2004): Fire Safety Journal. Retrieved from http://www.sciencedirect.com/science/article/pii/S0379711206000221

http://ac.els-cdn.com/S0379711206000221/1-s2.0-S0379711206000221-main.pdf?_tid=57a5fb8a-99ac-11e4-953e-00000aab0f26&acdnat=1420992801_727a3ec2c03219cc8729e8180697c882

The Geneva Association Staff. (2014). World Fire Statistics: Fire and Climate Control. Retrieved from https://www.genevaassociation.org/media/874729/ga2014-wfs29.pdf

Turekova, I., & Balog, K. (2010). The Environmental Impact of Fire-Fighting Foams: Faculty of Materials Science and Technology, Slovak University of Technology. Retrieved from https://www.mtf.stuba.sk/docs/doc/casopis_Vedecke_prace/29/12_turekova.pdf

http://www.degruyter.com/dg/viewarticle.fullcontentlink:pdfeventlink/$002fj$002frput.2010.18.issue-29$002fv10186-010-0033-z$002fv10186-010-0033-z.pdf?t:ac=j$002frput.2010.18.issue-29$002fv10186-010-0033-z$002fv10186-010-0033-z.xml

U.S. Department of Agriculture. (2014). Federal Firefighting Costs (Suppression Only). Retrieved from http://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf

U.S. Department of Energy. (2012). Buildings Energy Data Book (B. T. Program, Trans.). Washington DC: Pacific Northwest National Laboratory. Retrieved from http://buildingsdatabook.eere.energy.gov/

United Nations Human Settlements Programme (2011). [Housing Statistics]. Web Page.

United States Department of Commerce. (2012). Table 982. Total Housing Inventory for the United States: 1990 to 2010. Retrieved from http://www.census.gov/compendia/statab/2012/tables/12s0982.pdf

United States Fire Administration. (1987). Sherwin-Williams Paint Warehouse Fire. Retrieved from http://www.usfa.fema.gov/downloads/pdf/publications/tr-009.pdf

United States Geological Survey. (2009). *Emissions from Coal Fires and Their Impact on the Environment*. Retrieved from http://pubs.usgs.gov/fs/2009/3084/pdf/fs2009-3084.pdf.

Valeo, C., Beaty, K., & Hesslein, R. (2003). Influence of Forest Fires on Climate Change Studies in the Central Boreal Forest of Canada. *Journal of Hydrology, 280*, 91-104. Retrieved from http://www.sciencedirect.com/science/article/pii/S0022169403001859

van der Veen, I., & de Boer, J. (2012). Phosphorus flame retardants: Properties, production, environmental occurrence, toxicity and analysis. *Chemosphere, 88*, 1119-1153. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653512004353

Vikelsøe, J., & Johansen, E. (2000). Estimation of dioxin emission from fires in chemicals. *Chemosphere, 40*, 165-175. Retrieved from http://www.sciencedirect.com/science/article/pii/S0045653599002313

Wang, G., Yu, X., Bao, K., Xing, W., Gao, C., Lin, Q., & Lu, X. (2014). Effect of fire on phosphorus forms in Sphagnum moss and peat soils of ombrotrophic bogs. *Chemosphere, 119*(1), 1329-1334. Retrieved from http://dx.doi.org/10.1016/j.chemosphere.2014.01.084

Warner, M. L., & Preston, E. H. (1974). A Review of Environmental Impact Assessment Methodologies (Vol. EPA-600/5-74-002). Washington D.C.: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9101BOX1.txt

Western Forestry Leadership Coalition. (2010). The True Cost of Wildfire in the Western U.S. Retrieved from http://www.wflccenter.org/news_pdf/324_pdf.pdf

Wieczorek, C. J., Ditch, B., & Bill Jr, R. G. (2010). Environmental Impact of Automatic Fire Sprinklers:

Part 2. Experimental Study. *Fire Technology*, 765-779. Retrieved from http://link.springer.com/article/10.1007%2Fs10694-010-0192-7

Wilson, R. D. (1998). Interim Air Quality Policy on Wildland and Prescribed Fires. Research triangle, NC: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100JSKT.txt

World Bank (1999). [Content of an Environmental Assessment Report for a Category A Project]. Web Page.

Yamate, G. (1973). Development of Emission Factors for Estimating Atmospheric Emissions from Forest Fires (Vol. EPA-450/3-72-009). Research Triangle Park, N.C.: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=9100ZRUK.txt

Yamate, G. (1974). Emissions Inventory from Forest Wildfires, Forest Managed burns, and Agricultural Burns (Vol. EPA-450/3-74-062). Research Triangle , N.C.: Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000Z8K9.txt

Yates, J. (1989). Phillips Petroleum Chemical Plant Explosion and Fire: U.S. Fire Administration. Retrieved from http://www.usfa.fema.gov/downloads/pdf/publications/tr-035.pdf

Yefremov, D. F., & Shvidenko, A. Z. (2004). Long-term Environmental Impact of Catastrophic Forest Fires in Russia'a Far East and their Contribution to Global Processes (Vol. 32): International Forest Fire News. Retrieved from http://www.fire.uni-freiburg.de/iffn/iffn_32/06-Yefremov.pdf

Yue, X., Mickley, L. J., Logan, J. A., & Kaplan, J. O. (2013). Ensemble projections of wildfire activity and carbonaceous aerosol concentrations over the western United States in the mid-21st century. *Atmospheric Environment, 77*, 767-780. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231013004573#

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3763857/pdf/nihms494592.pdf