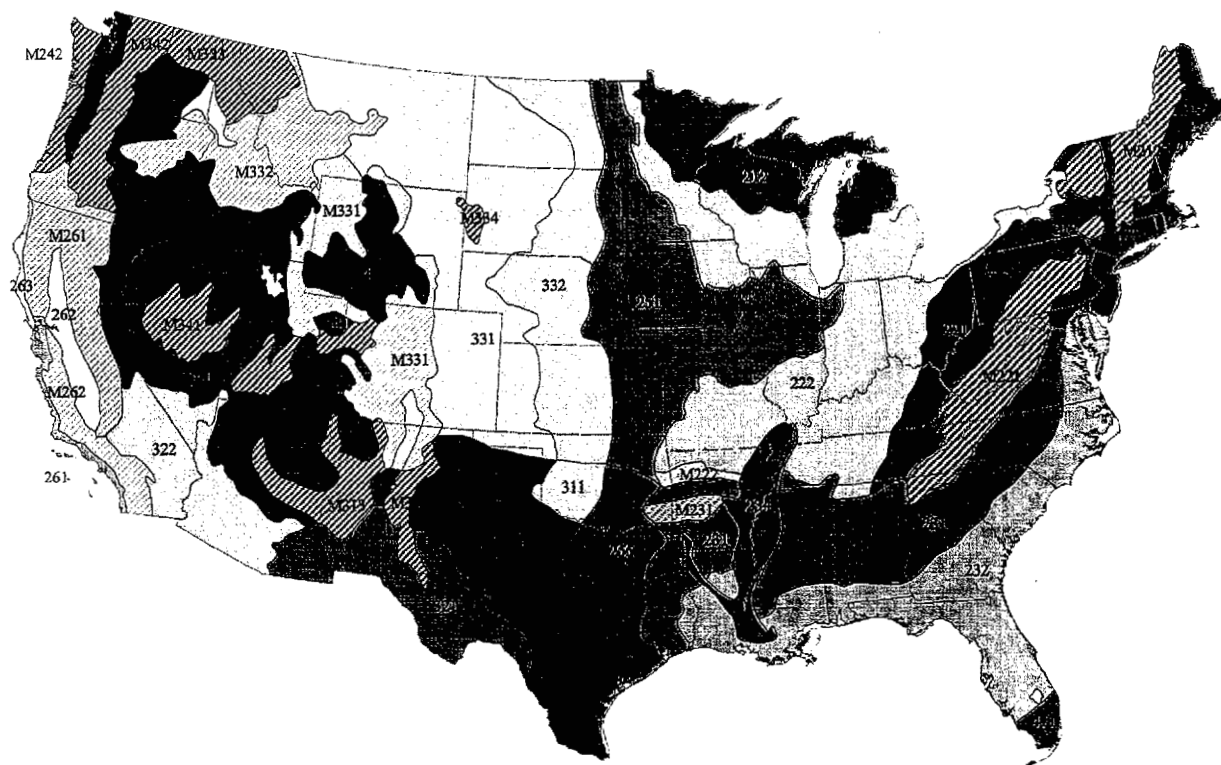


Health and Environmental Sciences Department
Publication Number 4684
March 1999



American Petroleum Institute

Environmental, Health, and Safety Mission and Guiding Principles

MISSION

The members of the American Petroleum Institute are dedicated to continuous efforts to improve the compatibility of our operations with the environment while economically developing energy resources and supplying high quality products and services to consumers. We recognize our responsibility to work with the public, the government, and others to develop and to use natural resources in an environmentally sound manner while protecting the health and safety of our employees and the public. To meet these responsibilities, API members pledge to manage our businesses according to the following principles using sound science to prioritize risks and to implement cost-effective management practices:

PRINCIPLES

- To recognize and to respond to community concerns about our raw materials, products and operations.
- To operate our plants and facilities, and to handle our raw materials and products in a manner that protects the environment, and the safety and health of our employees and the public.
- To make safety, health and environmental considerations a priority in our planning, and our development of new products and processes.
- To advise promptly, appropriate officials, employees, customers and the public of information on significant industry-related safety, health and environmental hazards, and to recommend protective measures.
- To counsel customers, transporters and others in the safe use, transportation and disposal of our raw materials, products and waste materials.
- To economically develop and produce natural resources and to conserve those resources by using energy efficiently.
- To extend knowledge by conducting or supporting research on the safety, health and environmental effects of our raw materials, products, processes and waste materials.
- To commit to reduce overall emission and waste generation.
- To work with others to resolve problems created by handling and disposal of hazardous substances from our operations.
- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Compilation and Review of Data on the Environmental Effects of *In Situ* Burning of Inland and Upland Oil Spills

Health and Environmental Sciences Department

API PUBLICATION NUMBER 4684

PREPARED UNDER CONTRACT BY:

JEFFREY A. DAHLIN
SCOTT ZENGEL
CARRIE HEADLEY
JACQUELINE MICHEL
RESEARCH PLANNING, INC.
1121 PARK STREET
COLUMBIA, SOUTH CAROLINA 29201

MARCH 1999

FOREWORD

API PUBLICATIONS NECESSARILY ADDRESS PROBLEMS OF A GENERAL NATURE. WITH RESPECT TO PARTICULAR CIRCUMSTANCES, LOCAL, STATE, AND FEDERAL LAWS AND REGULATIONS SHOULD BE REVIEWED.

API IS NOT UNDERTAKING TO MEET THE DUTIES OF EMPLOYERS, MANUFACTURERS, OR SUPPLIERS TO WARN AND PROPERLY TRAIN AND EQUIP THEIR EMPLOYEES, AND OTHERS EXPOSED, CONCERNING HEALTH AND SAFETY RISKS AND PRECAUTIONS, NOR UNDERTAKING THEIR OBLIGATIONS UNDER LOCAL, STATE, OR FEDERAL LAWS.

NOTHING CONTAINED IN ANY API PUBLICATION IS TO BE CONSTRUED AS GRANTING ANY RIGHT, BY IMPLICATION OR OTHERWISE, FOR THE MANUFACTURE, SALE, OR USE OF ANY METHOD, APPARATUS, OR PRODUCT COVERED BY LETTERS PATENT. NEITHER SHOULD ANYTHING CONTAINED IN THE PUBLICATION BE CONSTRUED AS INSURING ANYONE AGAINST LIABILITY FOR INFRINGEMENT OF LETTERS PATENT.

All rights reserved. No part of this work may be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the publisher, API Publishing Services, 1220 L Street, N.W., Washington, D.C. 20005.

Copyright © 1999 American Petroleum Institute

ACKNOWLEDGMENTS

THE FOLLOWING PEOPLE ARE RECOGNIZED FOR THEIR CONTRIBUTIONS OF TIME AND EXPERTISE DURING THIS STUDY AND IN THE PREPARATION OF THIS REPORT:

API STAFF CONTACT

Alexis E. Steen, Health and Environmental Sciences Department

MEMBERS OF THE INLAND SPILLS WORKGROUP

David E. Fritz, Work Group Chair, Amoco Corporation

Andrie C.T. Chen, Exxon Production Research Company

Donald K. Erickson, Bay West, Inc.

Jack Farlow, U.S. EPA

Robert J. Fiocco, Exxon Research and Engineering Company

Richard M. Gaudiosi, U.S. Coast Guard

Ronald H. Goodman, Imperial Oil Ltd.

John Kimball, TriData, Inc.

Jerry Langley, Williams Pipeline Company

Zelvin Levine, U.S. Department of Transportation

Ken D. Ratliff, Phillips Petroleum Company

Gail Thomas, U.S. EPA

James Sanders, CITGO Pipeline

Dana Slade, Lakehead Pipeline Company

Dot Zaino (RPI) is recognized for her contributions to the final preparation of this work.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
EXECUTIVE SUMMARY	ES-1
1. PURPOSE OF THE STUDY.....	1-1
2. <i>IN SITU</i> BURN CASE HISTORIES	2-1
INTRODUCTION	2-1
METHODS	2-1
Identification and Collection of Data	2-1
SUMMARY OF CASE STUDIES	2-6
3. <i>IN SITU</i> BURNING OBSERVATIONS AND LESSONS LEARNED.....	3-1
REASONS FOR BURNING	3-1
Burning Removes the Oil Quickly, Preventing the Spread of Oil Into More Sensitive Environments or Over Large Areas	3-1
Burning Reduces the Amount of Oily Waste for Collection and Disposal.....	3-1
There is Limited Access to the Spill Site, Reducing the Feasibility of Mechanical or Manual Recovery	3-2
Burning is a Final Measure or Last Resort, When Mechanical Cleanup Methods Lose Their Effectiveness or Pose a Greater Threat to the Environment.....	3-2
CONDITIONS FOR BURNING	3-2
The Burn Site is Remote or Sparsely Populated	3-3
Woody Vegetation (Trees and Shrubs) is Absent	3-3
The Spill Site Consists of Open Fields.....	3-4
The Spill Site Consists of Crop Lands.....	3-4
The Spill is in an Area Devoid of Vegetation.....	3-4
The Plants Are Dormant Which May Minimize Vegetation Impacts and Accelerate Recovery	3-4



TABLE OF CONTENTS

	<u>Page</u>
For Marsh Areas, the Substrate is Submerged Beneath a Water Level.....	3-5
Snow and Ice Cover Provides Natural Containment and Protects the Substrate	3-5
The Winds Are Calm	3-5
The Spilled Materials Are Unweathered Oils or Light Products Which Are Most Effectively Burned.....	3-6
Marshes Should Not be Burned if a Sustained Increase in Water Level is Anticipated Following Burning	3-6
PUBLIC HEALTH AND SAFETY ISSUES.....	3-6
Request and Obtain the Necessary Permission to Proceed with the <i>In Situ</i> Burn.....	3-6
Develop a Burn Plan and Present It to the Regulatory Authorities so They Can Review and Modify It Before the Burn Event.....	3-7
Notify Local Emergency Authorities Prior to the Burn.....	3-7
Provide Appropriate Site Security and Prevent Public Access to the Burn Site.....	3-7
PRE-BURN CONSIDERATIONS.....	3-8
Immediately Prior to Burning, Survey the Entire Area to be Burned and Implement Necessary Precautions.....	3-8
Avoid Physical Disturbance of Vegetation or Substrate.....	3-8
If Spilled Oil Will Not Ignite Readily, It May be Necessary to Use Ignitors or Accelerants	3-8
Ignite the Downwind Side of the Burn Area First, Allowing the Fire to Spread Upwind.....	3-9

TABLE OF CONTENTS

	<u>Page</u>
POST-BURN CONSIDERATIONS.....	3-9
Following the Burn, Patrol the Entire Area Carefully to Identify Remaining Oil, Residue, and “Hot Spots” That Could Flare Up Again.....	3-9
A Crust (Residue) is Typically Formed on Burned Soil That Retards Re-vegetation, and Thus May Need to be Broken Up or Removed ..	3-9
Erosion May be a Problem in Burn Areas Where Plants Were Damaged or Killed.....	3-10
Vegetation in and Adjacent to the Burn Site Can be Affected.....	3-10
Burning Can Alter Vegetation Community Types.....	3-10
Burning Can Severely Impact Organic Soils Such as Those Found in Peat Bogs, Muskey Swamps, or Fens	3-10
4. SUMMARIES OF FIRE ECOLOGY AND PRESCRIBED BURNING	4-1
INTRODUCTION	4-1
METHODS	4-1
GENERAL POINTS ON FIRE ECOLOGY AND PRESCRIBED BURNING ...	4-5
General Prescribed Fire Guidelines from Wright and Bailey.....	4-5
Fire Ecology, Effects, and Management Points from Whelan.....	4-6
5. FIRE ECOLOGY AND EFFECTS SUMMARIES FOR INDIVIDUAL PLANT SPECIES.....	5-1
SUMMARIES FOR MAJOR PLANT SPECIES OF U.S. ECOREGIONS.....	5-1
Trees/Forests.....	5-2
Shrubs and Associated Communities	5-2
Grasses/Grasslands.....	5-3
Desert Habitats/Cacti	5-4

TABLE OF CONTENTS

	<u>Page</u>
FIRE EFFECTS SUMMARIES FOR WETLAND GRASSES AND SEDGES	5-4
6. CONCLUSIONS ON THE ENVIRONMENTAL EFFECTS OF <i>IN SITU</i> BURNING	6-1
REFERENCES	R-1
Appendix A LIST OF CONTACTS	A-1
Appendix B INCIDENT SUMMARY SHEETS	B-1
Appendix C <i>IN SITU</i> BURN OBSERVATION CHECKLIST	C-1

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2-1. Types of Environments Where <i>In Situ</i> Burning of Spilled Oil Was Conducted; Includes Spills Where Multiple Environments Were Burned....	2-7
2-2. Range of Volume of Oil Burned, for the 18 Cases Where the Volume Burned Was Known.....	2-7
2-3. Types of Oil Burned for the 31 Cases Included in This Analysis	2-8
4-1. Ecoregion Provinces for the Conterminous United States	4-3

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2-1. Summary list of <i>in situ</i> burn cases included in this report.....	2-3
4-1. Major plant species by ecoregion, cross-referenced by community type	4-9
5-1. Fire ecology and effects summaries for major plant species of U.S. ecoregions	5-7
5-2. Fire ecology and effects summaries for selected wetland grasses and sedges of North America (including Alaska)	5-48



LIST OF ABBREVIATIONS

API	- American Petroleum Institute
bbl	- barrel(s)
BTEX	- Benzene, Toluene, Ethyl benzene, and Xylene; Volatile Hydrocarbons
cm	- centimeter
dbh	- diameter at breast height
ERNS	- Emergency Response Notification System
FEIS	- Fire Effects Information System
km	- kilometer
L	- Liters
m	- meter
mg	- milligram
mg/m ³	- milligram per cubic meter
mph	- miles per hour
m/s	- meters per second
NIST	- National Institute of Standards and Testing
NOAA	- National Oceanic and Atmospheric Administration
PAH	- Polynuclear aromatic hydrocarbons
ppm	- parts per million
RRT	- Regional Response Team
TPH	- Total petroleum hydrocarbons
USDA	- U.S. Department of Agriculture
USEPA	- U.S. Environmental Protection Agency
USFWS	- U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

The primary objective of this study was to identify those environmental conditions under which burning should be considered as a response option for oil spilled in inland and upland habitats. Two very different approaches were used: 1) documenting the "state of the practice" for spills where burning was used; and 2) extracting guidelines from the extensive literature on fire ecology and prescribed burning of vegetation. Combined, these two approaches provide the best available guidance on when burning should and should not be considered for a specific spill in inland and upland areas.

Previous literature searches, recent publications, and personal contacts were used to identify 31 case histories of spills or experiments where oil was burned in inland and upland habitats. These case histories were reviewed in Section 2 to identify the conditions under which oil has been burned in the past. Generally, burns were conducted mostly in marshes and open fields. Nearly half of the burns of a known volume of spilled oil were for quantities of less than 1,500 liters. The most common type of oil burned was crude oil; there was only one case where a heavy crude oil was burned. Short summaries were prepared (Appendix B) to document the spill conditions, an evaluation of the burn, and any follow-up monitoring results. Unfortunately, there have been very few spills where post-burn monitoring was conducted for any period of time. Burning, especially of small spills, is routinely conducted in some states, but there is little documentation available other than the fact that the oil was burned. Because of the focus on environmental issues, those relating to human health and air quality were not extensively addressed in this study. It should also be noted that there are few data on health concerns since most burns are conducted in remote areas.

However, the case histories do provide information on the state of the practice in terms of how *in situ* burning is used in inland and upland areas, which is presented in Section 3. In the past, spilled oil has been burned for the following reasons:

- To quickly remove oil to prevent its spread to sensitive sites or over larger areas

- To reduce the generation of oily wastes, especially where transportation or disposal options were limited
- Where access to the site was limited, by shallow water, soft substrates, or the remoteness of the location
- As a final removal technique, when other methods began to lose effectiveness or become too intrusive

The following favorable conditions for burning were identified from the case histories:

- Remote or sparsely populated sites
- Mostly herbaceous vegetation (with few trees or shrubs)
- Plants are dormant
- Unvegetated areas, such as ditches, dry streambeds, etc.
- In wetlands, presence of a water layer covering the substrate
- In cold areas, presence of snow and ice which provides natural containment and substrate protection
- Calm winds
- Spills of fresh crudes or light refined products

Sections 4 and 5 present applicable information gleaned from the field of fire ecology and prescription burning. Prescribed fires are often used as a forest and range management tool, and are often conducted for the same reasons as *in situ* burning: fire can be less damaging, more effective, and less costly than chemical and intrusive mechanical methods. The fire ecology literature was searched for both general guidelines as well as species-specific profiles on fire ecology and effects, providing excellent guidelines on the effects of burning (in the absence of oil) on plant communities. There are many lessons already learned by fire practitioners and ecologists which are directly applicable to the use of *in situ* burning of spilled oil. These lessons apply to conditions when a burn should/should not be considered (e.g., soil type and moisture, droughts), the conducting of actual burn events (e.g., the direction of the burn and how to control the burn intensity), as well as post-burn considerations (e.g., the potential for erosion and over-grazing).

The U.S. Department of Agriculture maintains a Fire Effects Information System which includes data on the fire ecology and adaptations of numerous plant species, including post-fire regeneration strategy, immediate fire effect, plant response to fire, fire management considerations, and fire case studies. Information on fire effects and ecology of more than 200 dominant plant species of the United States were summarized from this database in Section 5. These summaries should provide spill responders with better information on the potential response of different habitat types and plant species to *in situ* burning.

The conclusions of the study on the environmental effects of *in situ* burning in inland and uplands areas are presented in Section 6. Burning is a valuable tool under many conditions, such as: in locations at a distance from populated areas; for spills of light to medium oils; when the oil is likely to spread to more sensitive or larger areas; at sites with restricted access; and where other options are likely to be very intrusive and cause more harm. However, there is still insufficient documentation to answer some of the key questions likely to be asked by resource managers and agency representatives. Only through better documentation and monitoring will the response community be able to confidently state the conditions under which burning is an appropriate response tool.

Section 1

PURPOSE OF THE STUDY

Burning of spilled oil provides a relatively easy, low cost cleanup method by eliminating removal, transportation, and disposal costs, as well as reducing the time required for cleanup. There is a strong opinion among oil spill professionals that *in situ* burning of oiled habitats is a viable alternative which can, when used properly, minimize the kinds of environmental impacts associated with mechanical and manual removal efforts. In a guide rating the environmental effects of response options (American Petroleum Institute and National Oceanic and Atmospheric Administration, 1994), *in situ* burning was favorably ranked as a response option for many of the more sensitive inland and upland habitats. However, such "alternative" response options are generally considered on a case-by-case basis until there is sufficient field experience for the response community to confidently make routine decisions on when to use them.

Although published information on burning of spilled oil in inland and upland sites is very limited, there was a general sense in the response community that, perhaps, unpublished experiences of the use of burning existed in the files and records of government response agencies and oil production and transportation companies. This study was commissioned by the American Petroleum Institute (API) to locate and obtain this potentially valuable resource of unpublished information on use of burning as a spill response tool in inland and upland areas. A parallel effort was made to review and summarize information on the effects of fire and prescribed burning on different upland and wetland vegetation types in the absence of oil. General fire ecology and prescribed burning documents were reviewed, and a national database on fire effects was consulted. This report presents a summary of the case histories and lessons learned from previous uses of burning in inland environments, with and without oil. While some information on human health and safety is included, the focus of this report is on the environmental fate and effects of *in situ* burning. For more information on inhalation hazards from smoke particles and other emissions from burning oil, refer to Fingas *et al.* (1993, 1994) and Benner *et al.* (1990).

Section 2

IN SITU BURN CASE HISTORIES

INTRODUCTION

The initial focus of this study was to compile and summarize case histories of *in situ* burning of oil in inland and upland environments. By integrating case history information for various spill scenarios and habitat types, it was thought that meaningful *in situ* burn guidelines could be developed for inland and upland areas. *In situ* burning case summaries and lessons learned are provided below. Because of the general lack of good documentation for most spills where burning was used during the response, it is suggested that better documentation of inland and upland *in situ* burns in the future could greatly increase the knowledge base.

METHODS

Identification and Collection of Data

The data collection effort focused on information on *in situ* burning in inland and upland environments, including brackish and freshwater wetlands. The primary contacts for identifying or collecting data were federal agencies, state agencies, and petroleum corporations. A list of the people and organizations contacted during this study is provided in Appendix A. The federal agencies contacted were:

- National Institute for Standards and Testing (NIST)
- National Oceanic and Atmospheric Administration (NOAA)
- Transportation Safety Institute
- U.S. Coast Guard
- U.S. Environmental Protection Agency (USEPA)
- U.S. Fish and Wildlife Service (USFWS)

The states contacted were:

- Alaska
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Minnesota
- Missouri
- Ohio

- Oklahoma
- North Dakota
- Pennsylvania
- Texas
- Wisconsin
- Wyoming

The oil and pipeline companies contacted were:

- Amoco
- Imperial Oil
- Lakehead Pipeline
- Marathon Oil
- Williams Pipeline

The following universities and land managers were contacted:

- Louisiana State University
- Rockefeller Wildlife Refuge (Louisiana state refuge)
- Texas A&M University

Two recent computerized literature searches on *in situ* burning of oil spills (Mendelsohn *et al.*, 1995; S.L. Ross, 1996) were utilized to identify case studies where *in situ* burning of oil spills had been conducted. This information was also updated with papers from the 1997 Oil Spill Conference session on *in situ* burning. Information from other sources and contacts included monitoring, survey, and research reports, USEPA spill reports [downloaded from the Emergency Response Notification System (ERNS) database], state spill reports, and anecdotal information from telephone interviews.

A brief summary of each case history for *in situ* burning in inland and upland areas was prepared, including as much information as available on the amount of oil burned, the habitats burned, and observations on the effectiveness and effects of the burn (Appendix B). The case studies are listed in Table 2-1 in alphabetical order using the spill name. References for each case study are listed in each summary. Based on these case studies, the “state of the practice” in terms of the key considerations for burning oil was summarized. A checklist for observing burns was also developed (Appendix C). The checklist should provide a quick and easy method of documenting

Table 2-1. Summary list of *in situ* burn cases included in this report.

Spill	Location	Spill Volume (Liters)	Oil Type	Environment	Volume Burned (Liters)*	Time till Burn (Days)*	Substrate*	Vegetation
Black Lake	West Hackberry, LA	11,447,086	Light Arabian Crude	Lacustrine and Fringing Marsh	?	?	?	Herbaceous
Brunswick Naval Air Station	Brunswick, ME	240,389	JP-5	Freshwater Marsh	79,494	8	?	Herbaceous
California Crude Spill	California	794,937	Heavy Crude Oil	Dry Creek Bed, Unvegetated	954	?	?	None
Chilipin Creek	Copano Bay, TX	469,013	South Texas Light Crude	Brackish to Salt-water Marsh	182,835	?	?	Herbaceous
ESSO Bayway	Port Neches, TX	1,040,572	Light Arabian Crude	Saltwater Marsh	?	?	Water	No
Friendship II Pipeline	Kékcse, Hungary	422,470	Russian Crude Oil	Peat Bog	4,823	?	Peat	Herbaceous
Imperial Oil Calgary	British Columbia	133,549	South Louisiana Crude	Freshwater Bog	?	?	Peat	Woody/Herbaceous
Kolva River Basin Pipeline Site 5	Komi Republic, Russia	Large Volume	Crude Oil and Formation Water	Muskeg	?	?	Peat	
Lafitte Site 1	Lafitte, LA	159	South Louisiana Crude	Brackishwater Marsh	?	?	?	Herbaceous
Lafitte Site 2	Lafitte, LA	44,834	South Louisiana Crude	Brackishwater Marsh	?	?	?	Herbaceous
Lafitte Site 3	Lafitte, LA	636	South Louisiana Crude	Brackishwater Marsh	?	?	?	Herbaceous
Marathon Pipeline, Gillespie Facility	Bridgeton, IL	795	Crude Oil	Cultivated Field, Unvegetated	159	0.5	?	None
Marathon Pipeline, Noble Gathering	Noble, IL	795	Crude Oil	Cultivated Field, Unvegetated	477	0.5	Mud	None

Table 2-1. Continued.

Spill	Location	Spill Volume (Liters)	Oil Type	Environment	Volume Burned (Liters)	Time till Burn (Days)	Substrate	Vegetation
Marathon Pipeline, Noble S. Gathering	Cisne, IL	477	Crude Oil	Cultivated Field, Unvegetated	318	0.5	Mud	None
Marathon Pipeline, Patterson	Clay City, IL	795	Crude Oil	Cultivated Field, Unvegetated	525	1	Water	None
Marathon Pipeline, Roy Gill Site	Clay City, IL	79	Crude Oil	Cultivated Field, Corn Stalks	79	0.5	?	Corn Stalks
Marathon Pipeline, Sanders Lease	Allendale, IL	1,590	Crude Oil	Cultivated Field, Corn Stalks	79	0.5	?	Corn
Meire Grove	Meire Grove, MN	397,468	Fuel Oil and Gasoline	Freshwater Wetland and Pond	?	11	No	Herbaceous
Nipisi Bog Pipeline Spill	Alberta, Canada	9,539,238	Nipisi Crude Oil	Ombrotrophic Bog	2/158,987	1,551/?	Peat	?
Norsk Hydro Experiment	Spitsbergen, Iceland	954	Marine Diesel/Oseberg Crude Oil	Snow Covered Moraine	954	4-13	?	None
Old Peace River Fen Pipeline	Alberta, Canada	1,589,873	Nipisi Crude Oil	Wet Meadow/Thin Peat	?	365	Peat	Herbaceous
Pass-a-Loutre	Southeast Pass, LA	10000s	South Louisiana Crude	Brackishwater Marsh	?	?	?	Herbaceous
Rainbow Fen Pipeline	Alberta, Canada	3,179,746	Nipisi Crude Oil	Poor Fen	?	365	Peat	Herbaceous
Rockefeller Wildlife Refuge	Cameron Parish, LA	6,359	Condensate Oil	Brackishwater Marsh	4,770	5	?	Herbaceous
Siroco Pipeline	DeBerry, TX	7,949	Texas Sweet Crude Oil	Forested Upland/ Intermittent Creek	7,949	4	?	Woody/ Herbaceous

Table 2-1. Continued.

Spill	Location	Spill Volume (Liters)	Oil Type	Environment	Volume Burned (Liters)	Time till Burn (Days)	Substrate	Vegetation
Trans-Alaska Pipeline, Fairbanks	Fairbanks, AK	2,543,797	Prudhoe Bay Crude	Ponded Tundra	79,494	63	Tundra/Ice	Herbaceous
Vermillion 16	Freshwater City, LA	79,494	API 50 Condensate	Brackishwater Marsh	79,494	120?	?	Herbaceous
Warwick Lake	Ontario, Canada	58,825	Diesel Fuel	Wooded Upland/ Frozen Lake	58,825	>4	?	Woody/None
Williams Pipeline Co. Surface Spill Barnsdall	Barnsdall, OK	11,924	Jet Fuel	Open Field/Ditch/ Stream, Partially Vegetated	2,862	?	?	Herbaceous/ None
Williams Pipeline Co. Subsurface Gasoline	Mexico, MO	14,309	Gasoline	Open Field, Unvegetated	?	?	?	None

* ? indicates that the information was not provided in the references or by the interviewees.

the spill and burn, so that in the future, guidelines can be refined based on a larger, more substantial data set.

SUMMARY OF CASE STUDIES

Table 2-1 lists the 31 case histories of inland and upland *in situ* burns included in this report. There have been many more spills in which *in situ* burning was used as a cleanup method, but they were not included in this report because of the lack of documentation. Some states have allowed burning on a regular basis (Illinois, Kansas, Wyoming); however, the only documentation is the fact that product was spilled and then burned. The general guidelines for burning followed by these states have been: (1) the smoke plume should not impact any populated areas; and (2) oil recovery by other methods is not feasible, based on information provided by the Responsible Party. Typically if a burn site is at least 0.8 to 1.6 kilometers (km) from a populated area, burning has been allowed. These burns have usually been for spills of less than 800 liters (L) or about 5 barrels (bbl) of oil.

Most of the 31 spills included in this report are located in the U.S., but spills in Canada, Hungary, Norway, and Russia are also included. They cover geographic regions ranging from southern Texas to the Arctic Circle. Environmental regimes ranged from brackish and freshwater marshes to cultivated fields and dirt roads (Fig. 2-1). Volumes burned ranged from as little as 80 L to as much as several million liters (Fig. 2-2). The products burned were primarily light to medium crude oils or light refined products (Fig. 2-3).

Burns were conducted most frequently in marshes and open fields (Fig. 2-1). In most cases, the oil was burned because it was not possible or was extremely difficult to remove the oil by mechanical methods. In many cases, burning was a secondary treatment method once mechanical removal efforts were terminated, for whatever reason. In other cases, burning was used because it was the most expedient method for oil removal when time was short.

Nearly half of the burns of a known volume of spilled oil were for quantities less than 1,500 L (Fig. 2-2). Often, other techniques were used to remove the bulk of the spilled oil, and burning was used as a final removal method. Burning was used in areas where physical disruption of the substrate by mechanical or manual removal efforts was of concern, and burning was selected as an option to reduce the probability of the

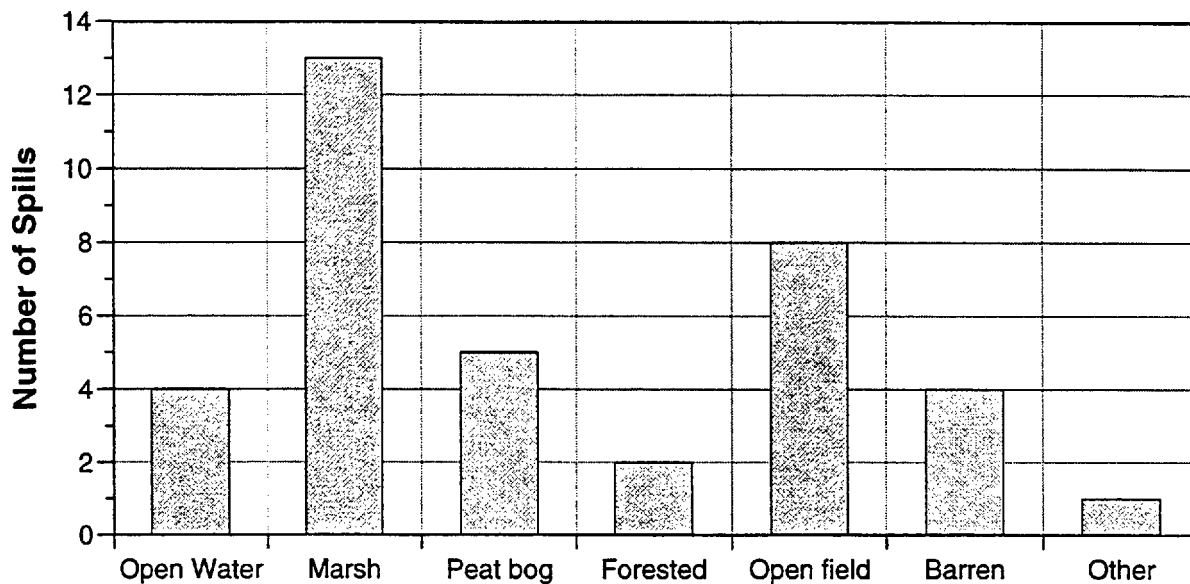


Figure 2-1. Types of Environments Where *In Situ* Burning of Spilled Oil Was Conducted; Includes Spills Where Multiple Environments Were Burned

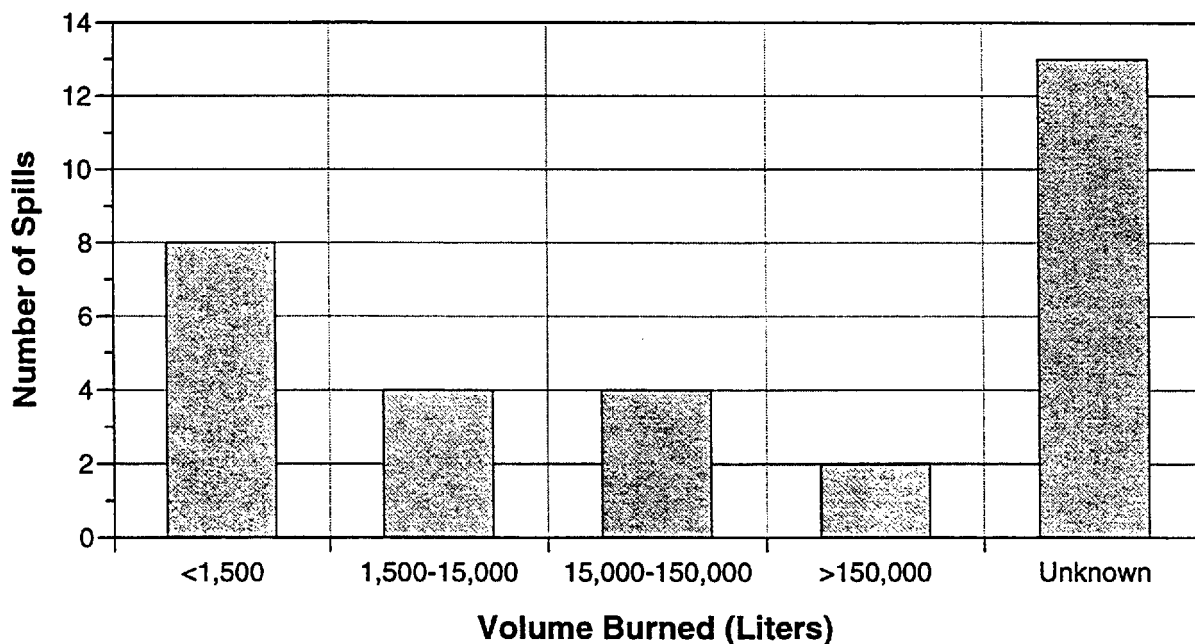


Figure 2-2. Range of Volume of Oil Burned, for the 18 Cases Where the Volume Burned Was Known

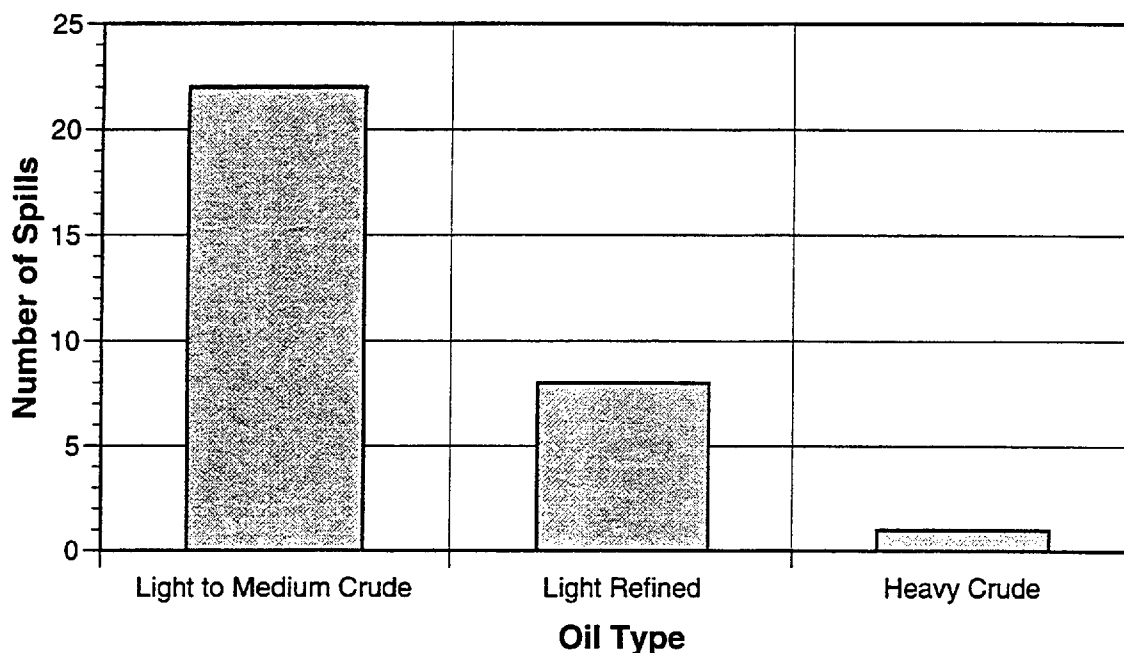


Figure 2-3. Types of Oil Burned for the 31 Cases Included in This Analysis

oil being forced further into the sediments as a result of cleanup efforts. For many of the spills where the volume burned was unknown, the original amount of oil spilled was very large. Based on the available information, it was not possible to estimate the amount burned.

The most common types of oil burned were medium or light crude oils. The remainder of the burns were of light refined products such as gasoline, diesel, or jet fuel. There were no reported cases where heavy refined products like Bunker C were burned. There was only one report where a heavy crude oil was burned, and the observation was that the heavy crude oil did not burn well. Heavy refined oil products are not often burned because of the difficulty of ignition and low removal efficiencies (Tom Lael, personal communication).

Section 3

IN SITU BURNING OBSERVATIONS AND LESSONS LEARNED

In this section, experiences gleaned from the reports on previous uses of *in situ* burning of inland and upland areas are summarized for the following topics:

- Reasons for burning
- Conditions for burning
- Public health and safety issues
- Pre-burn considerations
- Post-burn considerations

REASONS FOR BURNING

Selecting a response option during oil spill response requires evaluating spill-specific conditions and analyzing the pros and cons of various methods. In many places, open burning of oil is regulated by the state air quality agency and USEPA air quality guidelines. Before obtaining approval from these agencies, there needs to be strong justification for burning the oil, as opposed to other cleanup methods. The following discussion summarizes reasons that supported burning of spilled oil in the past.

Burning Removes the Oil Quickly, Preventing the Spread of Oil Into More Sensitive Environments or Over Large Areas

Burns typically last for only a few hours but are effective in removing large amounts of oil. If there is only a short window of opportunity (typically 1-2 days) to remove the oil from the environment before it causes significantly more damage, then burning becomes a viable possibility. With several of the cases (Gonzalez and Lugo, 1995; Hess *et al.*, 1997; May and Wolfe, 1997), rain was forecast for the near future and there was concern that the rain would flush the oil into more sensitive environments, or prevent removal of the oil. With the Williams Pipeline subsurface gasoline spill, the site geology/hydrology was not well understood (Williams Pipeline Company, undated report). There was concern that the product would migrate down gradient toward a nearby creek and impact surface water. Based on this information, the decision was made to burn the product to quickly remove it from trenches dug to intercept the oil on top of the ground water.

Burning Reduces the Amount of Oily Waste for Collection and Disposal

For the Warwick Lake spill in Ontario, Canada, the only way to and from the site was by small plane (Burns, 1988). Transporting large amounts of oil or oiled debris was

not feasible, therefore the decision to burn on-site was made. For the Trans-Alaska Pipeline spill, there was easy access via a road; however, with spring thaw, weight restrictions were placed on the road, preventing the transport of large amounts of oil (Buhite, 1979). As a result, approval was granted to burn the remaining oil at the site. With burning, there is often a residue, but this is usually only a fraction of the original volume.

There is Limited Access to the Spill Site, Reducing the Feasibility of Mechanical or Manual Recovery

The equipment required for burning is minimal compared to the equipment and personnel needed for mechanical or manual recovery, handling, and storage. Access may be limited by the surrounding terrain. In the case of the Brunswick spill, the oil was in a marsh where sediments would not support vehicular traffic (Eufemia, 1993). An existing dirt road was upgraded to allow access to one portion of the marsh, but the remaining wetlands were inaccessible. The site may also be in a very remote location, where the only access may be by small plane, as with the Warwick Lake spill in Canada (Burns, 1988). In this case, it was not possible to bring in any type of equipment, other than manpower.

Burning is a Final Measure or Last Resort, When Mechanical Cleanup Methods Lose Their Effectiveness or Pose a Greater Threat to the Environment

Imperial Oil in Canada (Moir and Erskin, 1994) used burning to remove oil from a peat bog because the pumping operation was drawing down the water level, and there was concern that the oil would penetrate the peat substrate. At the Rockefeller Refuge spill, conventional methods removed only 15,900 L (100 bbl), of an estimated 63,600 L (400 bbl) after seven days of effort. Burning of the residue was selected as the preferred alternative over more intrusive mechanical removal (Hess *et al.*, 1997). Many of the Marathon pipeline spills were land-based and relatively small [160-795 L (1-5 bbl)], where it was difficult to remove the oil by any other means. In some cases, vacuum trucks were used to recover the pooled oil, and the remainder was burned.

CONDITIONS FOR BURNING

There are numerous environmental conditions that influence effectiveness, safety, and the recovery of the habitat following *in situ* burning. Conditions that were reported as both favorable and unfavorable to burning are discussed below. In addition to the considerations listed below, it is also highly recommended that experienced wildfire experts and prescribed fire practitioners be consulted for guidance concerning burning

conditions, fire behavior, and fire control. There are also several modeling systems developed by the U.S. Forest Service and others that can be used to predict fire behavior and control, smoke production, fire effects, etc. For more information on fire management models and tools, consult "Fire Management Tools *Online*" at "<http://www.fire.org/perl/tools.cgi>." Models that could be adapted for *in situ* burn planning include: the BEHAVE Fire Behavior Prediction and Fuel Modeling System, the First Order Fire Effects Model (FOFEM), and others.

The Burn Site is Remote or Sparsely Populated

One of the major issues with burning is the human health risk associated with the smoke plume generated by the burning oil. Except for the Brunswick spill, all of the burns were in relatively remote locations. In contrast to the stated concern about the smoke plume, air monitoring was conducted at only two of the sites (Rockefeller Refuge and Brunswick Naval Air Station) that were reviewed in this study. Most of the available air quality data are from experimental spills where there are sufficient time and resources for implementing air monitoring programs by trained teams.

Woody Vegetation (Trees and Shrubs) is Absent

The advantages of non-wooded areas was not directly addressed in any of the reports, but can be inferred based on the actions at both wooded and non-wooded sites. Open areas allow easy monitoring of burning and reduce the chance of losing control of the burn. Fire breaks are more easily constructed in unwooded areas, thus reducing the risk of the fire spreading beyond the intended burn site. For example, the fire break at the Vermilion 16 spill (Henry, 1997) was constructed by flattening the marsh grass around the burn site with an airboat. Mendelssohn *et al.* (1995) also concluded that most wetlands with woody vegetation should not be burned, primarily because these areas take much longer to recover, compared to herbaceous wetlands. In wooded areas, intense fire may scorch or ignite trees, possibly damaging or killing them, and may also start secondary, uncontrolled burns. There were two cases where burning was conducted in wooded areas (Moir and Erskin, 1994; Labay, 1997). In the Imperial Oil and SIROCO Pipeline cases, the condition that made the burns possible was heavy rains in the areas just prior to the burn. The ground and vegetation were very wet and not likely to burn; therefore, a controlled burn was more feasible. In wooded areas, a large firebreak needs to be constructed to contain the fire to prevent unintentional burning of the trees. In the Imperial Oil case study, the firebreak was

3-6 m wide. Even then, there was mortality to trees near the burn site as a result of heat stress (Moir and Erskin, 1994).

The Spill Site Consists of Open Fields

Protective equipment can be easily staged around a burn site in open fields, and the area is typically free of physical obstructions for isolating the burn area. At the Williams Pipeline spill in Barnsdall, Oklahoma (Williams Pipeline Company, undated report), the fire department was present during the spill and controlled the heat of the burn under some power lines. In addition, burning is a common management technique for open fields, and they usually recover quickly. The area can be tilled, fertilized, and re-seeded to enhance degradation of any oil residues and prepare the site for re-vegetation.

The Spill Site Consists of Crop Lands

Most crop lands have annual vegetation, so impacts to these environments as a result of burning usually last less than one year. Normal cleanup methods are complicated by the terrain in plowed fields. Based on the Marathon Pipeline Company burns, it is difficult to recover the last remaining oil from spills in fields. The fields are typically far enough from human habitation so as not to present a health risk, and it is easy to control the burn area. For the case histories studied, the burns were conducted in winter or early spring when the fields were either bare or had stubble from the previous crop; thus, no live vegetation was impacted. Following the burns, the area was tilled, limed, fertilized, and then farmed normally the next season.

The Spill is in an Area Devoid of Vegetation, e.g., Roads, Ditches, and Dry Stream Beds

There is no vegetation to be impacted in these areas, although wildlife in the area would have to be considered. Additional fuel may be needed to promote the burn in the absence of vegetation. Oil may remain in the sediment after the burn, but most of the free surface oil is usually removed. Depending on the substrate, it is expected that the oil will only penetrate a few centimeters (Burns, 1988), and have moderate concentrations (1,000 ppm) (May and Wolfe, 1997).

The Plants Are Dormant Which May Minimize Vegetation Impacts and Accelerate Recovery

Mendelssohn *et al.* (1995) concluded that *in situ* burns in marshes are less damaging when the vegetation is dormant. During dormancy, energy reserves are stored in plant

roots and rhizomes. After burning, plants can sprout using these stored reserves. During the growing season, energy reserves have been directed toward shoot growth and may not be available for re-growth after fire. Thus, plant recovery may be slowed or reduced. In the case histories, marshes burned during the dormant season showed rapid regrowth during the subsequent growing season (Pahl *et al.*, 1997; Buhite, 1979).

For Marsh Areas, the Substrate is Submerged Beneath a Water Layer

A water layer serves several purposes. It insulates the substrate from the heat of the burn to prevent destruction of plant roots and ignition of organic soils. It also serves as a barrier preventing oil from being driven into the substrate during the burn. The Kolva River Basin muskeg swamp had little water on it and the heat from the burn drove the oil into the peat mat (Hartley, 1996). There has been relatively good success with having as little as 5 to 10 centimeters (cm) of water over the substrate (Hess *et al.*, 1997). In all of the sites that had a water layer at the beginning of the burn, a water layer remained following the burn. Few reports documented the water depth, and no requirements for a prescribed minimum water depth for conducting a burn were found.

Snow and Ice Cover Provides Natural Containment and Protects the Substrate

Snow acts as a natural sorbent (Burns, 1988). When ignited, snow melts, releasing oil which then burns (Sveum *et al.*, 1991). Usually there is sufficient heat generated by burning oil to continue melting the snow and releasing oil. Unoiled snow also serves to contain the fire (Eufemia, 1993). Ice is considered an impermeable barrier, and as such can be used to concentrate oil for burning in open water conditions (Buhite, 1979; Eufemia, 1993). Burning can also create a wicking effect and remove large amounts of oil from under ice. Ice can protect the substrate during burning (Buhite, 1979) and may also reduce vegetation impacts.

The Winds Are Calm

Burns should be conducted with current and forecasted winds less than 5 m/s [11 miles per hour (mph)] and preferably less than 2.5 m/s (5.5 mph). In the reviewed reports, the winds were almost always below 5 m/s. Under calm conditions, smoke has a high vertical rise (assuming no inversions), dispersing them to safe concentrations. Where human populations may be at risk, the wind direction and speed must be considered, so that it will carry the smoke away from the populated areas (Eufemia, 1993). Low wind speed makes it easier to control the actual burn as well.

The Spilled Materials Are Unweathered Oils or Light Products Which Are Most Effectively Burned

Light fuel oils such as diesel, jet fuel, and gasoline are relatively easy to ignite and can be burned days or weeks after a release (Eufemia, 1993; Burns, 1988). Light or medium crude oils burn well if ignited within days after release. Extreme cold or snow cover can extend this time frame to weeks or months [Buhite, 1979; Blenkinsopp *et al.*, 1996 ([Nipisi Bog Pipeline spill)]. Heavy refined oils and crude oils need to be ignited within days of being released to burn efficiently (May and Wolfe, 1997), otherwise they are extremely difficult to ignite. Typically, a large amount of accelerant needs to be added to begin the burn. A heavy viscous burn residue is produced (Hartley, 1996; Lael, 1997), which may be more difficult to remove than the original oil. Surviving vegetation may not be able to grow up through heavy residual crusts, and seeds and propagules may be prevented from contacting the soil and germinating. Even with lighter oils, as they weather, more residue is left following the burn.

Marshes Should Not be Burned if a Sustained Increase in Water Level is Anticipated Following Burning

Mendelssohn *et al.* (1995) concluded that post-burn water level increases could drastically impact burned marshes if the vegetation were completely submerged for several weeks. This may have been a factor in the poor recovery of burned marsh at the Port Neches, Texas spill (McCauley and Harrel, 1981).

PUBLIC HEALTH AND SAFETY ISSUES

The protection of public health and safety is of utmost importance during an *in situ* burn. Human health is not the focus of this report; however, public health and safety issues are discussed here as part of the overall response strategy. Lessons learned from the case histories are listed below.

Request and Obtain the Necessary Permission to Proceed With the *In Situ* Burn

Burning is a permitted means of mitigation in most states. It is necessary to carefully coordinate the burn with the governing agencies in the spill area, which may include the USEPA, state air quality control board, state environmental protection agencies, state natural resource agencies, and state and local health officials. It is important to follow the local guidelines, if any are in place, and any additional requirements set forth by any agency as deemed necessary for that particular spill location. These might include additional monitoring during and after the spill in heavily populated

areas, as well as extensive restoration in highly sensitive areas. Pre-approval areas or predefined decision-making procedures can expedite the entire approval process.

Develop a Burn Plan and Present It to the Regulatory Authorities so They Can Review and Modify It Before the Burn Event

The plan should take into consideration the environment in which the burn will be conducted, health and safety issues, details concerning the methodology to be followed, monitoring plans, and post-burn cleanup and monitoring. See the introductory paragraph under "Conditions for Burning" (page 3-2) for sources of information and tools to assist with burn planning.

Notify Local Emergency Authorities (Fire, Police, and Ambulance) Prior to the Burn

These authorities should be provided with the exact location and expected duration of the burn. The reason for this is twofold: (1) to dispel confusion; this will prevent the local authorities from thinking that the burn is an emergency situation; and (2) if any problems arise during the burn, the authorities will be able to respond more effectively. Local authorities can be requested to provide standby fire control at the burn site, but this should only be requested if responders deem it necessary. Many emergency response departments, especially in rural areas, do not have sufficient resources to provide extensive standby fire control. The Williams Pipeline Company alerted the local fire department of the burn conducted at the Barjenbruch property in Mexico, Missouri and the fire department was on-scene at their burn at the Barnsdall Station Property. Moir and Erskin (1994) report that fire fighting equipment was staged around the site to combat secondary fires. May and Wolf (1997) discuss the use of hand-held spray bottles to extinguish embers or any vegetation that catches fire outside of the burn area.

Provide Appropriate Site Security and Prevent Public Access to the Burn Site

Large burn events will likely draw spectators, thus all possible access points at the site must be controlled to assure public safety. The blockage of any public roads must be coordinated with local law enforcement officials prior to the burn. The Williams Pipeline Company blocked off several nearby roads and re-routed traffic away from the burn site during response efforts at the Barnsdall Station Property in Oklahoma (Williams Pipeline Company, undated report).

PRE-BURN CONSIDERATIONS

Once permission to conduct the burn is obtained, the following considerations are recommended prior to initiating the burn.

Immediately Prior to Burning. Survey the Entire Area to be Burned and Implement Necessary Precautions

For most spills, once the oil is ignited, it usually is not possible to extinguish the fire. All of the burns were allowed to go until they burned out. Any areas outside the proposed burn area that may be impacted by the burn should be wetted down or protected with a fire break. Fire breaks help control the spread of the fire and provide a buffer from the flames and excessive heat. Fire breaks have been used to protect surrounding woodland areas (Moir and Erskin, 1994), power lines (Eufemia, 1993), and pipelines (Buhite, 1979). They can be in the form of a trench, earthen berms (Moir and Erskin, 1994; Eufemia, 1993; Buhite, 1979), or by flattening marsh grasses (Henry, 1997). Eufemia (1993) pointed out that snow acts as an effective natural fire break and containment barrier. The herding of oil into certain areas within the proposed burn site is also a good idea to prevent adjacent trees, shrubs, utility wires, structures, etc. from being burned or scorched (Williams Pipeline Company, undated report [Barnsdall, Oklahoma]).

Avoid Physical Disturbance of Vegetation or Substrate

One of the objectives of a burn is to remove oil while minimizing physical destruction of the environment. In some cases, mechanical cleanup activities prior to the burn, or in preparation for the burn, have resulted in impacts to wetlands (Mendelssohn *et al.*, 1995). When it is evident that physical disruption of the vegetation or the substrate is occurring, activities should cease (Moir and Erskin, 1994; Eufemia, 1993).

If Spilled Oil Will Not Ignite Readily, It May be Necessary to Use Ignitors or Accelerants

The type of oil and degree of weathering affect the ignition process. If the spilled product cannot be readily ignited, a more flammable substance may be added to the spilled product. Accelerants may be added during the burn to maintain the fire. Various types of ignitors and accelerants have been used. Gasoline proved to be hazardous during the Imperial Pipeline spill (Moir and Erskine, 1994), so a mixture of gasoline and diesel was used. In the experiments conducted by Norsk Hydro, a petrol (gas) soaked rag was used successfully (Sveum *et al.*, 1991). Other ignitors include: varsol (Chilipin Creek, Texas); diesel (Lafitte Oil Field incidents); flares (Pass-a-Loutre, Louisiana; Trans-Alaska Pipeline incident, Alaska); blow torch (Barnsdall

Station Property Spill); burning hay (Rockefeller Refuge, Louisiana; Vermilion 16, Louisiana); and flame or drip torches. A common accelerant during prescribed burning includes 70:30 mixes of diesel and gasoline.

Ignite the Downwind Side of the Burn Area First, Allowing the Fire to Spread Upwind (Under Most Conditions)

Burning upwind produces a slower and more complete burn that is more easily controlled. However, a slower burn may cause greater damage to the vegetation and increase the risk of igniting organic soils, as a result of increased burn duration. Downwind ignition will also place the personnel lighting the fire downwind of the smoke and flames, so they should ensure that there is light wind during ignition. Lighting the fire on the upwind side can be hazardous, as it will likely produce a rapidly spreading and perhaps uncontrollable fire (May and Wolfe, 1997).

POST-BURN CONSIDERATIONS

Following the Burn, Patrol the Entire Area Carefully to Identify Remaining Oil, Residue, and "Hot Spots" That Could Flare Up Again

The area should be checked for residual oil or burn residue. Any remaining oil can either be re-ignited (Eufemia, 1993; Moir and Erskin, 1994; Pahl *et al.*, 1997) or removed with skimmers, sorbents, flushing, mechanical or manual efforts (Moir and Erskin, 1994; Williams Pipeline Company, undated reports). Removing oily residues is difficult or impossible in remote areas or soft substrates (Hartley, 1996). Once the burn is terminated, hot spots should be extinguished (wetted down or covered with earth).

A Crust (Residue) is Typically Formed on Burned Soil That Retards Re-vegetation, and Thus May Need to be Broken Up or Removed

There is usually some post-burn residue, particularly for black oils. The burn residue composition is similar to heavily weathered oil which is slightly enriched in high molecular weight aromatic hydrocarbons (Henry, 1993). All sediment samples collected in the case histories revealed the presence of residual contamination post-burn. On land, this crust (and underlying substrate) should be tilled or removed and fertilized soon after the burn (Buhite, 1979; May and Wolfe, 1997; Moir and Erskin, 1994; Williams Pipeline Company, undated report for the Barnsdall Station Property, Oklahoma) to promote the re-colonization of plants. In wetland environments, it may be necessary for cleanup crews to re-enter the burn area and remove the burn residue

(Gonzalez and Lugo, 1995). Another form of burn residue is soot (Henry, 1993; 1997), though it is not likely to be a source of long-term sediment contamination.

Erosion May be a Problem in Burn Areas Where Plants Were Damaged or Killed

Erosion control measures may be necessary, temporarily, until new vegetation is established at the burn site. Increased erosion may affect nearby water quality.

Inspect the burn area for potential erosion areas and take preventative actions. Both wind and water erosion should be considered. A variety of erosion control methods or devices are available, including mulching, biodegradable textiles, seeding with annual grasses such as rye, sediment fencing, etc. Erosion control measures often need to be tailored to the specific site location and conditions. Local soil conservation, forestry, or range management officials can often provide guidance on appropriate and effective erosion control measures.

Vegetation in and Adjacent to the Burn Site Can be Affected

Obviously, the vegetation within the burn site is engulfed by flames and damaged to a certain degree. Vegetation adjacent to burn sites is often scorched by flames or stressed from the heat produced by the fire (Moir and Erskin, 1994; Labay, 1997). Therefore, some off-site re-vegetation efforts or monitoring may be required.

Burning Can Alter Vegetation Community Types

In some instances, burned areas will shift to a less diverse plant community, such as at the Chiltipin Creek, Texas site (Tunnell *et al.*, 1995; 1997). For intense, long duration-burns, pioneering species return first, with the climax species starting to take over in a few years. For areas with sensitive species, or where organic soils burn, long-term or permanent changes in plant communities could occur. Tunnell *et al.* (1997) predicted that it would take 7-8 years before the climax community structure returns at a high marsh burn site in Texas.

Burning Can Severely Impact Organic Soils Such as Those Found in Peat Bogs (Moir and Erskin, 1994), Muskeg Swamps (Hartley, 1996), or Fens

Fire can ignite organic sediments and consume them to the point of altering local topography. This can change hydrological conditions at a site, as well as alter the plant community. In addition, when organic soils burn, plant roots and rhizomes are usually destroyed, killing the vegetation. In some cases, fire may liquify the oil, allowing it to penetrate deeper into the sediments (Hartley, 1996).

In summary, there are four reasons for burning:

- Rapid oil removal,
- Reduction of oily wastes that require disposal,
- Site access is limited, and
- As a last resort response option.

Unweathered crude and light petroleum products are most effectively burned.

Favorable site conditions for burns include:

- Remote or sparsely populated,
- No woody vegetation,
- Open fields or crop lands,
- Devoid of vegetation,
- Plants are in a dormant state or submerged, and
- A layer of snow or ice protects substrates.

Weather also can influence burn results and consequences:

- Calm winds provide better conditions for plume rise, and
- Higher water levels, post-burn, may adversely affect vegetation recovery.

While this document primarily addresses environmental conditions, there are public health and safety concerns that should be considered. These can be addressed via:

- Preparing a burn plan for regulatory review,
- Obtaining appropriate permits,
- Notifying local emergency response authorities prior to a burn, and
- Providing site security and restricting public access.

Considerations for conducting an inland or upland burn include:

<u>Pre-burn</u>	<u>Post-burn</u>
Survey the area to be burned	Patrol the burn site
Implement precautions	Identify hot spots that may re-ignite
Avoid physical disturbance	Break or remove any crusting
May need ignitors or accelerators	Take erosion control measures
Ignite downwind	Potential re-vegetation efforts needed

While burning can provide environmental benefits, it can also modify soils and vegetation.

Section 4

SUMMARIES OF FIRE ECOLOGY AND PRESCRIBED BURNING

INTRODUCTION

In addition to the case histories of *in situ* burning in oiled environments, information on the effects of fire in the absence of oil, both wildfire and prescribed burning, was reviewed and summarized. There is unquestionably a much greater body of knowledge concerning general fire ecology and prescribed fire as a management tool, as compared to *in situ* burning as an oil spill cleanup technique. It is thought that this knowledge base could provide important lessons and guidelines that could be applied to the special case of *in situ* burning of oil. Interestingly, some of the reasons which support the use of prescribed fire as a forest and range management tool are similar to those which support *in situ* burning: fire may be more environmentally acceptable than other methods (namely chemical and intrusive mechanical treatments); burning may be more effective than other methods; and use of fire may be easier to implement and less costly than other methods, particularly for large areas, remote locations, and sites with limited access (Wright and Bailey, 1982). In addition, fire is a natural feature in many ecosystems. There is quite a range of fire tolerance and fire "adaptation" among different plant community types, depending to a large extent on past fire frequency and intensity. Some plant communities are eliminated or excluded from areas by fire, while others may even be referred to as "fire dependent", requiring fire for their continued existence and/or maintenance. Information concerning the ecology and effects of fire on different plant community types should be a valuable tool for spill responders considering *in situ* burning.

METHODS

Two major references were consulted for general information on fire ecology, fire effects, and prescribed burning (Wright and Bailey, 1982; Whelan, 1995). Major points from these sources are listed so that they can be quickly consulted when *in situ* burning is considered as a response option.

For individual plant species, the U.S. Department of Agriculture (USDA) Forest Service maintains a Fire Effects Information System (FEIS) which was used as the major source for reviewing and summarizing information on the ecology and effects of fire (Fischer, 1992). This database can be accessed over the world wide web (www) at the following address, "www.fs.fed.us/database/feis/welcome.htm". The FEIS

contains literature summaries and case histories from a wide body of sources. The FEIS database provides information on the effects of fire on plant species, wildlife species, and plant cover and community types. Currently, information on fire effects by plant community and cover type is limited, with much more information available for individual species of plants and animals. For plants, species lists can be viewed by plant growth form (tree, shrub, graminoid, forb, cactus, etc.) or in total. Major data categories for each plant species cover the following topics: plant distribution and occurrence; value and use; botanical and ecological characteristics; fire ecology; fire effects; and references. For fire ecology and effects, database fields include the following:

- fire ecology and adaptations
- post-fire regeneration strategy
- immediate fire effect
- plant response to fire
- fire management considerations
- fire case studies

Wright and Bailey (1982), McCune (1988), Cerulean and Engstrom (1995), and Whelan (1995) were consulted for additional information on the effects of fire on particular plant species and communities.

To determine which species of plants to examine in the FEIS database, an ecoregion approach (Bailey, 1983; 1995) was used to identify the major vegetation types and plant species for different ecological regions of the coterminous United States. Ecoregion provinces defined and mapped by the USDA Forest Service (Fig. 4-1) were examined, and the major plant species associated with each province were identified (McNab and Avers, 1994; Bailey, 1995).

Plant species included in the fire effects summaries are listed by ecoregion in Table 4-1, cross-referenced by community type. Cross-referenced community types correspond closely with vegetation classes defined by Kuchler (1964). Figure 4-1 (map) and Table 4-1 (species list) can be used in conjunction to initially determine general vegetation types and fire effects that might need to be considered when planning or initiating *in situ* burning. All plant communities and species that may be prominent in particular areas are not represented, just the major groups listed by McNab and Avers (1994) or Bailey (1995). Species listed for some regions may also

be abundant in adjacent regions, or in other regions with similar vegetation communities. Note also that vegetation groups can occur in combination in some locations (e.g., oak-hickory-pine forest and bluestem prairie occur together as a mosaic in parts of ecoregion #222).

In addition to major vegetation types by ecoregion, fire effects summaries for wetland grasses and sedges were also prepared, since the feasibility of burning oil in marshes and similar habitats is high. Species from across North America (including Alaska) were chosen from wetland species listed in the FEIS database.

GENERAL POINTS ON FIRE ECOLOGY AND PRESCRIBED BURNING

Major points from Wright and Bailey (1982) and Whelan (1995) are listed below, concerning general fire ecology, fire effects, and prescribed burning.

General Prescribed Fire Guidelines from Wright and Bailey (1982)

It is important to have personnel trained and experienced in prescribed burning on-site if ecological, environmental, and safety considerations are to be adequately treated. The use of prescribed burning practitioners was not identified in any of the *in situ* burn case histories (Sections 2 and 3); however, they could provide highly valuable knowledge, skills, and experience that spill responders may not possess.

To minimize harmful ecological effects, prescribed fire should rarely be used during extended droughts or dry periods.

Ground temperature (in the root zone) influences plant impact and survival more so than surface temperatures or aboveground temperatures.

Temperature and duration of exposure influence plant impact and survival more so than maximum temperature or temperature level alone (similar to the dose concept in toxicology, where the concentration and duration of exposure are considered, e.g., 24-hr LC₅₀).

Soil moisture is an important factor during prescribed burns; higher soil moisture protects the vegetation from root damage and also protects organic soils.

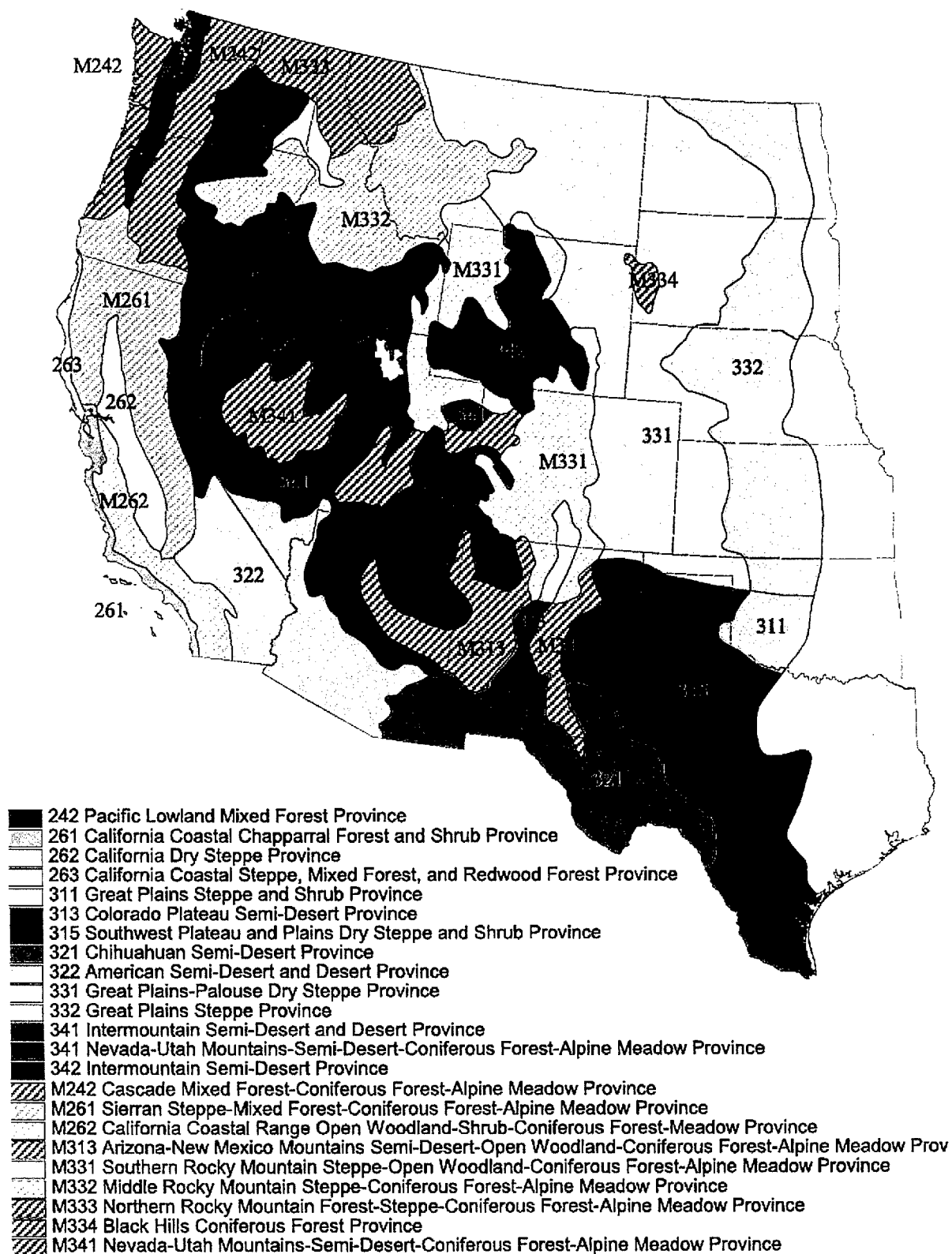
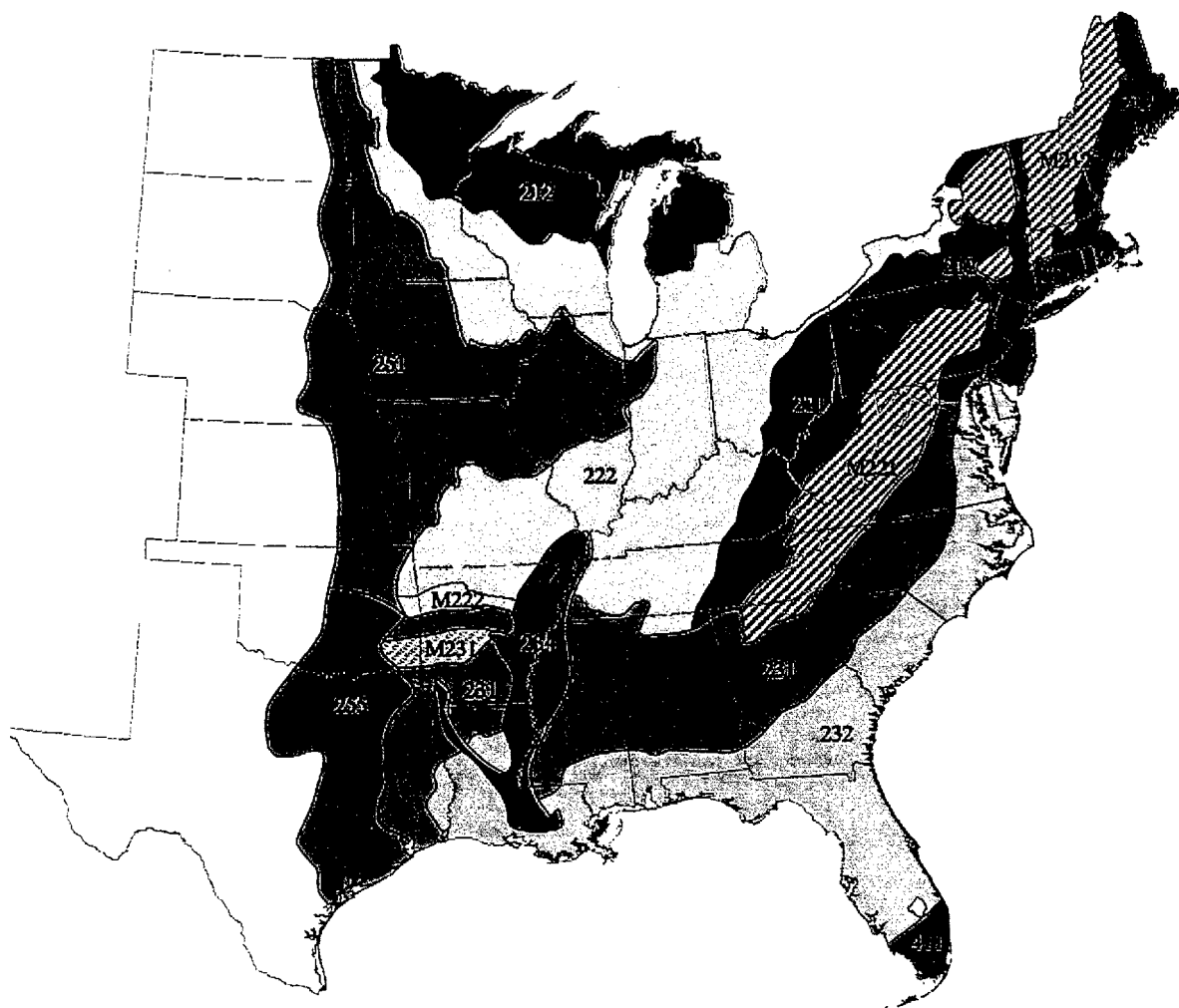


Figure 4-1. Ecoregion Provinces for the Coterminous United States (Bailey, 1995)



- 212 Laurentian Mixed Forest Province
- 221 Eastern Broadleaf Forest (Oceanic) Province
- 222 Eastern Broadleaf Forest (Continental) Province
- 231 Southeastern Mixed Forest Province
- 232 Outer Coastal Plain Mixed Forest Province
- 234 Lower Mississippi Riverine Forest Province
- 251 Prairie Parkland (Temperate) Province
- 255 Prairie Parkland (Subtropical) Province
- 411 Everglades Province
- M212 Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow Province
- M221 Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow Province
- M222 Ozark Broadleaf Forest - Meadow Province
- M231 Ouachita Mixed Forest - Meadow Province

Figure 4-1. Continued

Soil organic content is an important factor during burning; inorganic soils are good insulators; organic soils, especially dry organic soils, can ignite and be consumed by some fires, causing severe vegetation and site impacts.

Fuel load is an important factor when burning; higher fuel loads and more flammable fuels result in hotter, more intense, and potentially more damaging fires. Fire fuel commonly refers to live and dead plant material, litter, etc., but in the case of *in situ* burning would also include the spilled oil.

Potential for wind and water erosion should be considered during and after prescribed burns.

Soil loss or erosion following fire is affected by ground slope, plant cover type, the amount and size of bare areas, and storm (rainfall) intensity. The steeper the ground slope, the greater potential for erosion, especially if vegetation and litter are removed by fire. Heavy rains following burning can result in substantial erosion in some settings.

Fire can increase water yield from burned areas, increasing run-off.

Fire can negatively impact water quality and aquatic organisms in adjacent water bodies by affecting turbidity, sedimentation, water levels, water temperature, dissolved oxygen, nutrients, etc.

Burning up steep slopes is similar to burning in windy conditions; fires spread rapidly and can become intense and difficult to control.

Fire Ecology, Effects, and Management Points from Whelan (1995)

Direct fire tolerance in plants revolves around three characteristics: protection of sensitive (meristematic) plant tissues in insulating bark; protection of sensitive plant tissues in belowground parts insulated by soil; and the bearing of sensitive plant tissues at a height above the zone of fire impact. These characteristics may occur individually or in combination for plants described as fire tolerant.

In many trees, bark thickness is a major determinant of fire tolerance. Similarly, seedling, saplings, and young trees are often less fire resistant than larger trees since bark thickness increases with tree size.

Grasses (and similar monocots, such as sedges) have meristems (primary growth tissue) occurring at the leaf base while dicots (such as most flowering trees and shrubs) have meristems exposed and elevated as the plant grows. Therefore grasses, especially those with clump and tussock growth forms, often have sensitive growth tissues protected from fire, in contrast to many other plants.

Some woody plants, especially shrubs, “sacrifice” sensitive aboveground tissues to fire, but still tolerate fire by sprouting from previously suppressed buds in underground stems and roots insulated by soil.

Soil is a good insulator; plant parts buried deeper than 5 cm rarely experience significantly elevated temperatures as a result of fire.

Seasonality is important to consider during burning; many plants are more or less susceptible to fire damage, and more or less likely to recover, during different seasons. Seasonal factors to consider include: wet vs. dry season fire, dormant vs. growing season fire, and natural fire season vs. out of season fire (for fire prone communities).

During the dormant season, carbohydrate reserves are stored in roots or rhizomes and are available for sprouting either immediately after fire or during the onset of the next growing season. During the growing season, these reserves have been directed towards shoot growth, and little is available to support regrowth following fire. Growing season burns may eliminate, reduce, or slow plant recovery.

The natural fire season is an important consideration for fire-prone communities. Plants in fire-prone communities may have critical life-history periods timed to the season of natural fire occurrence; out of season fires may interfere with this timing, resulting in lesser fire tolerance, or reduced or slowed recovery.

Fire type is important. Example 1—slow-moving low intensity fires may in some cases be more damaging to vegetation than hot fast-moving fires (e.g., a slow, cool burn that consumed organic soil down to the bedrock could be more damaging to forest

vegetation than an intense crown fire). Example 2—back-fires, ignited on the downwind side of the area to be burned, may be more damaging to trees than head-fires, ignited on the upwind side of the area to be burned, because they subject tree trunks to elevated temperatures for longer time-periods.

Fire frequency and recent fire history is important. A fire that occurs after another fire or series of fires may be more damaging than typically expected if plant or community characteristics such as belowground reserves, seedbank development, soil moisture, etc. have not returned to certain levels. Note that natural fire frequencies can vary widely for different plant species and communities, some may be burned annually, while others may typically burn only once in 10, 25, 100, or 500 years. Some plant communities can be burned annually for, say, three consecutive years, but will fail to recover if burned for four consecutive years.

Similar to the concept above, other disturbances or stresses either before, concurrent with, or after burning can affect vegetation recovery. The most often mentioned factor is grazing (especially over-grazing) after burning, since herbivores may be attracted to burned sites by increased access or new growth. Other factors might include other physical site disturbances, draining, drought, flooding, pest or pathogen infestation, pesticide application, etc.

The physical structure of the plant community, such as vertical layering, can be an important factor when burning. Trees in forests with open understories of low grasses and shrubs may be minimally affected by surface fires. In contrast, forests with well developed mid-story vegetation layers or dense shrub layers can result in fires that spread upwards into the canopy and tree crowns, damaging or killing large numbers of mature trees.

Exotic and/or nuisance species must be considered in some locations so that burning does not enhance their establishment or spread, especially since many of these species establish on disturbed sites, and some may be fire “adapted”. As an example, Australian Melaleuca in southern Florida both establishes on disturbed sites and is proliferated by fire. Another example is Saltcedar, which may invade or dominate riparian areas in the southwestern United States following fire disturbance.

Table 4-1. Major plant species by ecoregion (McNab and Avers, 1994; Bailey, 1995), cross-referenced by community type. Ecoregion identification numbers prefixed by an "M" refer to mountain provinces, with different zones of vegetation occurring at different elevation levels.

Scientific Name	Common Name	Community Types
EcoRegion #212		
<i>Abies balsamea</i>	Balsam fir	Northern hardwood-spruce forest, northeastern spruce-fir forest, Great Lakes pine forest, Great Lakes spruce-fir forest
<i>Acer saccharum</i>	Sugar maple	Northern hardwood forest, northern hardwood-spruce forest, northeastern spruce-fir forest, Great Lakes pine forest, Great Lakes spruce-fir forest
<i>Betula alleghaniensis</i>	Yellow birch	Northern hardwood forest, northern hardwood-spruce forest, northeastern spruce-fir forest, Great Lakes spruce-fir forest
<i>Fagus grandifolia</i>	American beech	Northern hardwood forest, northern hardwood-spruce forest, northeastern spruce-fir forest, Great Lakes pine forest
<i>Picea rubens</i>	Red spruce	Northern hardwood-spruce forest, northeastern spruce-fir forest
<i>Pinus strobus</i>	Eastern white pine	Northern hardwood forest, northern hardwood-spruce forest, northeastern spruce-fir forest, Great Lakes pine forest, Great Lakes spruce-fir forest
<i>Tsuga canadensis</i>	Eastern hemlock	Northern hardwood forest, northern hardwoods-spruce forest, northeastern spruce-fir forest, Great Lakes pine forest, Great Lakes spruce-fir forest
Ecoregion #M212		
<i>Abies balsamea</i>	Balsam fir	Northern hardwood-spruce forest, northeastern spruce-fir forest
<i>Acer saccharum</i>	Sugar maple	Northern hardwood, northern hardwood-spruce, northeastern spruce-fir forest
<i>Betula alleghaniensis</i>	Yellow birch	Northern hardwood forest, northern hardwood-spruce forest, northeastern spruce-fir forest
<i>Fagus grandifolia</i>	American beech	Northern hardwood forest, northern hardwood-spruce forest, northeastern spruce-fir forest
<i>Picea rubens</i>	Red spruce	Northern hardwood-spruce forest, northeastern spruce-fir forest
<i>Tsuga canadensis</i>	Eastern hemlock	Northern hardwood forest, northern hardwoods-spruce forest, northeastern spruce-fir forest
Ecoregion #221		
<i>Acer saccharum</i>	Sugar maple	Mixed mesophytic forest
<i>Aesculus sp.</i>	Sweet buckeye	Mixed mesophytic forest
<i>Chamaecyparis thyoides</i>	Atlantic white-cedar	Pine-oak forest (mesic sites)

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #221 (continued)		
<i>Fagus grandifolia</i>	American beech	Mixed mesophytic forest
<i>Liriodendron tulipifera</i>	Tuliptree (yellow-poplar)	Mixed mesophytic forest
<i>Pinus echinata</i>	Shortleaf pine	Appalachian oak forest
<i>Pinus rigida</i>	Pitch pine	Pine-oak forest (pine barrens)
<i>Quercus alba</i>	White oak	Mixed mesophytic forest, Appalachian oak forest
<i>Quercus coccinea</i>	Scarlet oak	Appalachian oak forest
<i>Quercus ilicifolia</i>	Bear oak	Pine-oak forest (pine barrens)
<i>Quercus marilandica</i>	Blackjack oak	Pine-oak forest (pine barrens)
<i>Quercus rubra</i>	Northern red oak	Mixed mesophytic forest, Appalachian oak forest
<i>Quercus stellata</i>	Post oak	Appalachian oak forest
<i>Quercus velutina</i>	Black oak	Appalachian oak forest
<i>Sassafras albidum</i>	Sassafras	Pine-oak forest (pine barrens)
<i>Tilia americana</i>	American basswood	Mixed mesophytic forest
<i>Tsuga canadensis</i>	Eastern hemlock	Mixed mesophytic forest
<i>Vaccinium pallidum</i>	Blue Ridge (hillside) blueberry	Pine-oak forest (pine barrens)
Ecoregion #M221		
<i>Acer rubrum</i>	Red maple	Oak-hickory-pine forest
<i>Abies fraseri</i>	Fraser's fir	Southeastern spruce-fir forest
<i>Acer saccharum</i>	Sugar maple	Northern hardwood forest
<i>Betula alleghaniensis</i>	Yellow birch	Northern hardwood forest
<i>Carya alba (tomentosa)</i>	Mockernut hickory	Oak-hickory-pine forest
<i>Carya glabra</i>	Pignut hickory	Oak-hickory-pine forest
<i>Fagus grandifolia</i>	American beech	Northern hardwood forest
<i>Liriodendron tulipifera</i>	Tuliptree (yellow-poplar)	Mixed mesophytic forest
<i>Picea rubens</i>	Red spruce	Northeastern spruce-fir forest, southeastern spruce-fir forest
<i>Pinus echinata</i>	Shortleaf pine	Oak-hickory-pine forest
<i>Pinus strobus</i>	Eastern white pine	Northern hardwood forest
<i>Quercus alba</i>	White oak	Mixed mesophytic forest, Appalachian oak forest, oak-hickory-pine forest
<i>Quercus coccinea</i>	Scarlet oak	Appalachian oak forest
<i>Quercus marilandica</i>	Blackjack oak	Oak-hickory-pine forest

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #M221 (continued)		
<i>Quercus rubra</i>	Northern red oak	Mixed mesophytic forest, Appalachian oak forest
<i>Quercus stellata</i>	Post oak	Oak-hickory-pine forest
<i>Quercus velutina</i>	Black oak	Appalachian oak forest
<i>Tilia americana</i>	American basswood	Mixed mesophytic forest, northern hardwood forest
<i>Tsuga canadensis</i>	Eastern hemlock	Northern hardwood forest
<i>Vaccinium pallidum</i>	Blue Ridge (hillside) blueberry	Appalachian oak forest, oak-hickory-pine forest
Ecoregion #222		
<i>Acer saccharum</i>	Sugar maple	Beech-maple forest, maple-basswood forest
<i>Andropogon gerardii</i>	Big bluestem	Bluestem (tallgrass) prairie
<i>Carya alba (tomentosa)</i>	Mockernut hickory	Oak-hickory forest
<i>Carya cordiformis</i>	Bitternut hickory	Oak-hickory forest
<i>Carya glabra</i>	Pignut hickory	Oak-hickory forest
<i>Carya ovata</i>	Shagbark hickory	Oak-hickory forest
<i>Cornus florida</i>	Flowering dogwood	Oak-hickory forest
<i>Fagus grandifolia</i>	American beech	Beech-maple forest
<i>Fraxinus pennsylvanica</i>	Green ash	Northern floodplain forest
<i>Juniperus virginiana</i>	Eastern redcedar	Cedar glades, oak-hickory forest
<i>Liriodendron tulipifera</i>	Tuliptree (yellow-poplar)	Oak-hickory forest
<i>Liquidambar styraciflua</i>	Sweetgum	Oak-hickory forest
<i>Ostrya virginiana</i>	Eastern hophornbeam	Oak-hickory forest
<i>Panicum virgatum</i>	Switchgrass	Bluestem (tallgrass) prairie
<i>Pinus echinata</i>	Shortleaf pine	Oak-hickory forest
<i>Platanus occidentalis</i>	American sycamore	Northern floodplain forest
<i>Populus deltoides</i>	Eastern cottonwood	Northern floodplain forest
<i>Quercus alba</i>	White oak	Oak-hickory forest
<i>Quercus coccinea</i>	Scarlet oak	Oak-hickory forest
<i>Quercus marilandica</i>	Blackjack oak	Oak-hickory forest
<i>Quercus rubra</i>	Northern red oak	Oak-hickory forest
<i>Quercus stellata</i>	Post oak	Oak-hickory forest
<i>Quercus velutina</i>	Black oak	Oak-hickory forest
<i>Sassafras albidum</i>	Sassafras	Oak-hickory forest

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #222 (continued)		
<i>Salix nigra</i>	Black willow	Northern floodplain forest
<i>Schizachyrium scoparium</i>	Little bluestem	Bluestem (tallgrass) prairie, cedar glades
<i>Sorghastrum nutans</i>	Indiangrass	Bluestem (tallgrass) prairie
<i>Spartina pectinata</i>	Prairie cordgrass	Bluestem (tallgrass) prairie
<i>Sporobolus heterolepis</i>	Prairie dropseed	Bluestem (tallgrass) prairie
<i>Tilia americana</i>	American basswood	Maple-basswood forest
<i>Ulmus americana</i>	American elm	Oak-hickory forest, northern floodplain forest
Ecoregion #M222		
<i>Carya glabra</i>	Pignut hickory	Oak-hickory forest, oak-hickory-pine forest
<i>Carya alba (tomentosa)</i>	Mockernut hickory	Oak-hickory forest, oak-hickory-pine forest
<i>Juniperus virginiana</i>	Eastern redcedar	Oak-hickory forest
<i>Pinus echinata</i>	Shortleaf pine	Oak-hickory-pine forest
<i>Quercus alba</i>	White oak	Oak-hickory forest
<i>Quercus coccinea</i>	Scarlet oak	Oak-hickory-pine forest
<i>Quercus marilandica</i>	Blackjack oak	Oak-hickory-pine forest
<i>Quercus rubra</i>	Northern red oak	Oak-hickory forest
<i>Quercus stellata</i>	Post oak	Oak-hickory-pine forest
<i>Quercus velutina</i>	Black oak	Oak-hickory forest
Ecoregion #231		
<i>Acer rubrum</i>	Red maple	Oak-hickory-pine forest, southern mixed forest
<i>Andropogon gerardii</i>	Big bluestem	Bluestem-sacahuista prairie
<i>Callicarpa americana</i>	American beautyberry	Oak-hickory-pine forest, southern mixed forest
<i>Carya alba (tomentosa)</i>	Mockernut hickory	Oak-hickory-pine forest, southern mixed forest
<i>Carya glabra</i>	Pignut hickory	Oak-hickory-pine forest, southern mixed forest
<i>Cornus florida</i>	Flowering dogwood	Oak-hickory-pine forest, southern mixed forest
<i>Ilex vomitoria</i>	Yaupon	Oak-hickory-pine forest, southern mixed forest
<i>Liquidambar styraciflua</i>	Sweetgum	Oak-hickory-pine forest, southern mixed forest
<i>Nyssa sylvatica</i>	Black gum (tupelo)	Oak-hickory-pine forest, southern mixed forest
<i>Panicum virgatum</i>	Switchgrass	Bluestem-sacahuista prairie
<i>Pinus echinata</i>	Shortleaf pine	Oak-hickory-pine forest, southern mixed forest
<i>Pinus taeda</i>	Loblolly pine	Oak-hickory-pine forest, southern mixed forest

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #231 (continued)		
<i>Quercus alba</i>	White oak	Oak-hickory-pine forest, southern mixed forest
<i>Quercus marilandica</i>	Blackjack oak	Oak-hickory-pine forest, southern mixed forest
<i>Quercus falcata</i>	Southern red oak	Oak-hickory-pine forest, southern mixed forest
<i>Quercus nigra</i>	Water oak	Oak-hickory-pine forest, southern mixed forest
<i>Quercus stellata</i>	Post oak	Oak-hickory-pine forest, southern mixed forest
<i>Ulmus alata</i>	Winged elm	Oak-hickory-pine forest, southern mixed forest
<i>Schizachyrium scoparium</i>	Little bluestem	Bluestem-sacahuista prairie
<i>Sorghastrum nutans</i>	Indiangrass	Bluestem-sacahuista prairie
<i>Vaccinium pallidum</i>	Blue Ridge (hillside) blueberry	Oak-hickory-pine forest, southern mixed forest
<i>Viburnum acerifolium</i>	Mapleleaf viburnum	Oak-hickory-pine forest, southern mixed forest
Ecoregion #M231		
<i>Carya alba (tomentosa)</i>	Mockernut hickory	Oak-hickory-pine forest
<i>Carya glabra</i>	Pignut hickory	Oak-hickory-pine forest
<i>Pinus echinata</i>	Shortleaf pine	Oak-hickory-pine forest
<i>Pinus taeda</i>	Loblolly pine	Oak-hickory-pine forest
<i>Quercus alba</i>	White oak	Oak-hickory-pine forest
<i>Quercus falcata</i>	Southern red oak	Oak-hickory-pine forest
<i>Quercus velutina</i>	Black oak	Oak-hickory-pine forest
Ecoregion #232		
<i>Acer rubrum</i>	Red maple	Southern mixed forest, southern floodplain forest
<i>Andropogon gerardii</i>	Big bluestem	Bluestem-sacahuista prairie
<i>Celtis laevigata</i>	Sugarberry	Southern floodplain forest
<i>Chamaecyparis thyoides</i>	Atlantic white-cedar	Southern floodplain forest, pocosin
<i>Cyrilla racemiflora</i>	Cyrilla (titi)	Pocosin
<i>Fraxinus pennsylvanica</i>	Green ash	Southern floodplain forest
<i>Ilex glabra</i>	Bitter gallberry	Pocosin
<i>Liquidambar styraciflua</i>	Sweetgum	Southern mixed forest, southern floodplain forest
<i>Magnolia grandiflora</i>	Southern magnolia	Southern mixed forest
<i>Magnolia virginiana</i>	Sweetbay	Southern floodplain forest, pocosin
<i>Myrica cerifera</i>	Wax myrtle (southern bayberry)	Pocosin

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #232 (continued)		
<i>Nyssa aquatica</i>	Water tupelo	Southern floodplain forest
<i>Nyssa biflora</i>	Swamp tupelo	Southern floodplain forest
<i>Nyssa sylvatica</i>	Black gum (tupelo)	Southern floodplain forest
<i>Panicum virgatum</i>	Switchgrass	Bluestem-sacahuista prairie
<i>Persea borbonia</i>	Red bay	Southern floodplain forest, pocosin
<i>Pinus elliotii</i>	Slash pine	Southern mixed forest
<i>Pinus palustris</i>	Longleaf pine	Southern mixed forest
<i>Pinus serotina</i>	Pond pine	Pocosin
<i>Pinus taeda</i>	Loblolly pine	Southern mixed forest
<i>Platanus occidentalis</i>	American sycamore	Southern floodplain forest
<i>Populus deltoides</i>	Eastern cottonwood	Southern floodplain forest
<i>Quercus laurifolia</i>	Laurel oak	Southern floodplain forest
<i>Quercus nigra</i>	Water oak	Southern mixed forest, southern floodplain forest
<i>Quercus texana</i>	Nuttall oak	Southern floodplain forest
<i>Quercus virginiana</i>	Live oak	Southern mixed forest
<i>Sabal palmetto</i>	Cabbage palm	Southern mixed forest
<i>Schizachyrium scoparium</i>	Little bluestem	Bluestem-sacahuista prairie
<i>Serenoa repens</i>	Saw palmetto	Southern mixed forest
<i>Sorghastrum nutans</i>	Indiangrass	Bluestem-sacahuista prairie
<i>Taxodium ascendens</i>	Pondcypress	Southern floodplain forest
<i>Taxodium distichum</i>	Baldcypress	Southern floodplain forest
<i>Ulmus americana</i>	American elm	Southern floodplain forest
Ecoregion #234		
<i>Acer rubrum</i>	Red maple	Southern floodplain forest
<i>Carya illinoensis</i>	Pecan	Southern floodplain forest
<i>Celtis laevigata</i>	Sugarberry	Southern floodplain forest
<i>Fraxinus pennsylvanica</i>	Green ash	Southern floodplain forest
<i>Liquidambar styraciflua</i>	Sweetgum	Southern floodplain forest
<i>Nyssa aquatica</i>	Water tupelo	Southern floodplain forest
<i>Nyssa biflora</i>	Swamp tupelo	Southern floodplain forest
<i>Platanus occidentalis</i>	American sycamore	Southern floodplain forest

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #234 (continued)		
<i>Populus deltoides</i>	Eastern cottonwood	Southern floodplain forest
<i>Quercus laurifolia</i>	Laurel oak	Southern floodplain forest
<i>Quercus nigra</i>	Water oak	Southern floodplain forest
<i>Quercus pagoda</i>	Cherrybark oak	Southern floodplain forest
<i>Quercus texana</i>	Nuttall oak	Southern floodplain forest
<i>Ulmus americana</i>	American elm	Southern floodplain forest
<i>Taxodium distichum</i>	Baldcypress	Southern floodplain forest
Ecoregion #242		
<i>Acer macrophyllum</i>	Bigleaf maple	Cedar-Hemlock-Douglas-Fir Forests, Oregon Oakwoods, Alder-Ash Forests
<i>Agrostis exarata</i>	Spike bentgrass	Cedar-Hemlock-Douglas Fir Forests, Oregon Oakwoods, Foothills Prairie
<i>Alnus rhombifolia</i>	White alder	Oregon Oakwoods, Alder-Ash Forests
<i>Alnus viridis ssp. sinuata</i>	Sitka alder	Cedar-Hemlock-Douglas Fir Forests
<i>Arbutus menziesii</i>	Pacific madrone	Cedar-Hemlock-Douglas Fir Forest, Oregon Oakwoods
<i>Dactylis glomerata</i>	Orchard grass	Introduced species, Willamette Valley Grasslands (foothills prairie)
<i>Danthonia intermedia</i>	Timber oatgrass	Foothills Prairie
<i>Danthonia spicata</i> var. <i>pinetorum</i>	Poverty oatgrass	Alder-Ash Forests
<i>Danthonia unispicata</i>	Onespike oatgrass	Foothills Prairie
<i>Deschampsia cespitosa</i>	Tufted hairgrass	Cedar-Hemlock-Douglas Fir Forest, Oregon Oakwoods, Alder-Ash Forest, Foothills Prairie
<i>Festuca idahoensis</i>	Idaho fescue	Foothills Prairie
<i>Koeleria macrantha</i>	Prairie junegrass	Foothills Prairie
<i>Populus trichocarpa</i>	Black cottonwood	Cedar-Hemlock-Douglas Fir Forests, Alder-Ash Forests
<i>Pseudotsuga menziesii</i> var. <i>menziesii</i>	Coastal Douglas fir	Cedar-Hemlock-Douglas Fir Forests, Oregon Oakwoods, Alder-Ash Forests
<i>Quercus garryana</i>	Oregon white oak	Cedar-Hemlock-Douglas Fir Forests, Oregon Oakwoods
<i>Salix lasiandra</i>	Pacific willow	Alder-Ash Forests
<i>Stipa columbiana</i>	Columbia needle grass	Foothills Prairie

Table 4-1. Continued.

Scientific Name	Common Name	Community Types
Ecoregion #242 (continued)		
<i>Stipa comata</i>	Needle and thread grass	Foothills Prairie
<i>Stipa thurberiana</i>	Thurber needle grass	Foothills Prairie
<i>Thuja plicata</i>	Western red cedar	Cedar-Hemlock-Douglas Fir Forests
<i>Tsuga heretophylla</i>	Western hemlock	Cedar-Hemlock-Douglas Fir Forests
Ecoregion #M242		
<i>Abies amabilis</i>	Pacific silver fir	Cedar-Hemlock-Douglas Fir Forest, Silver Fir-Douglas Fir Forest, Fir-Hemlock Forest, Western Spruce-Fir Forest, Spruce-Cedar-Hemlock Forest
<i>Abies concolor</i>	White fir	Lodgepole Pine-Subalpine Forest
<i>Abies grandis</i>	Grand fir	Cedar-Hemlock-Douglas Fir Forest, Silver Fir-Douglas Fir Forest, Western Spruce-Fir Forest, Spruce-Cedar-Hemlock Forest
<i>Abies lasiocarpa</i>	Subalpine fir	Fir-Hemlock Forest, Alpine Meadows and Barren
<i>Alnus rubra</i>	Red alder	Cedar-Hemlock-Douglas Fir Forest, Silver Fir-Douglas Fir Forest, Spruce-Cedar-Hemlock Forest
<i>Chamaecyparis nootkatensis</i>	Alaska cedar	Cedar-Hemlock-Douglas Fir Forest, Silver Fir-Douglas Fir Forest, Fir-Hemlock Forest, Western Spruce-Fir Forest, Spruce-Cedar-Hemlock Forest
<i>Picea engelmannii</i>	Engelmann spruce	Fir-Hemlock Forest, Alpine Meadows and Barren, Western Spruce-Fir Forest
<i>Picea sitchensis</i>	Sitka spruce	Cedar-Hemlock-Douglas Fir Forest, Spruce-Cedar-Hemlock Forest
<i>Pinus albicaulis</i>	Whitebark pine	Fir-Hemlock Forest, Western Spruce-Fir Forest, Lodgepole Pine-Subalpine Forest
<i>Pinus contorta</i> var. <i>contorta</i>	Shore pine	Silver Fir-Douglas Fir Forest, Fir-Hemlock Forest, Lodgepole Pine-Subalpine Forest, Spruce-Cedar-Hemlock Forest
<i>Pinus contorta</i> var. <i>murrayana</i>	Sierra lodgepole pine	Cedar-Hemlock-Douglas Fir Forest, Fir-Hemlock Forest, Western Spruce-Fir Forest, Lodgepole Pine-Subalpine Forest, Spruce-Cedar-Hemlock Forest
<i>Pinus ponderosa</i> var. <i>ponderosa</i>	Pacific Ponderosa pine	Cedar-Hemlock-Douglas Fir Forest