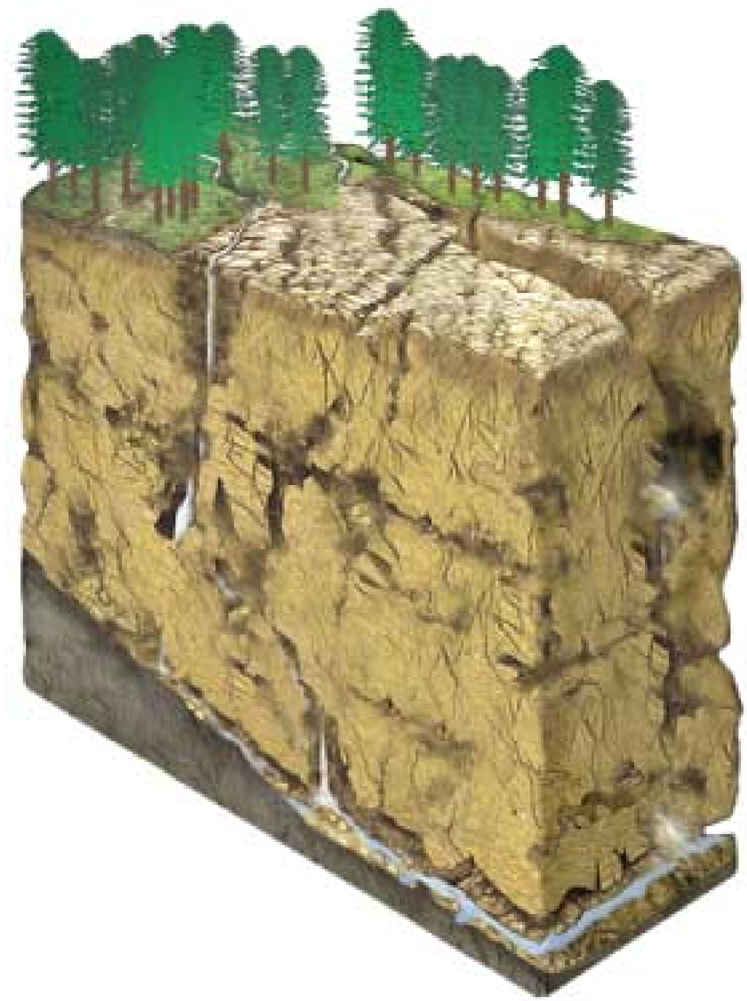
Karst Management Handbook for British Columbia



British Columbia

Ministry of Forests

May 2003

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Cover illustration: Graphic depiction of a cross-section of a forested karst landscape. The soil layer and forest cover have been removed in the right-hand foreground to expose the karst surface for illustrative purposes.

Preface

This handbook is intended to assist in the development of appropriate management practices when conducting forest operations on karst terrain. The information presented here is based on the best available knowledge from a number of different sources.

A great deal of valuable material was collected during a literature search from various jurisdictions around the world, particularly Tasmania and Alaska. Existing karst management practices used by the forest industry on Vancouver Island are also incorporated into the handbook, along with field observations from karst terrain on the Coast and in the Northern and Southern Interior. Throughout the development of the handbook, direct contact was made with several internationally recognized karst experts to obtain additional insights and recommendations.

The handbook is designed to be used in conjunction with the results of a karst field assessment as described in *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003).

While these best management practices are provincial in scope, it is recognized that British Columbia is very diverse in terms of topographic and climatic conditions, both of which can play a major role in karst development. As a result of this diversity, some of the recommended practices may be more applicable to some karst areas than others. For this reason, it is recommended that the handbook be implemented using an adaptive management approach. This will allow different regions of the province to exercise flexibility in applying and modifying the best management practices to meet local site conditions.

Much of the karst in northern British Columbia and the Interior is either above treeline or covered by a thick protective layer of soil and glacial till. The karst in these areas is generally less likely to be impacted by forestry activities than the karst along the coast, where soils tend to be thinner and surface karst features/attributes are more prevalent. As a result, use of the karst best management practices is expected to be significantly lower in northern and interior regions of the province compared to some coastal areas.

Application of the karst management handbook will rely heavily on professional judgement. Where site-specific knowledge or experience suggests other practices would better achieve management objectives, that information should take precedence. In some cases, difficult or complex management decisions may require additional input from karst specialists or other professionals.

As the handbook is implemented in various karst areas across British Columbia, the recommended best management practices will be refined and revised based on operational experience and user feedback. User feedback can be forwarded to: Forests.ForestPracticesBranchOffice@gems3.gov.bc.ca.

To make the handbook easier to read, specific citations are not included in the body of the text. However, a complete list of citations can be found in the reference section.

Acknowledgements

This project was initiated by Larry Pedersen, Chief Forester, and managed by Peter Bradford and Bill Marshall, Forest Practices Branch, Ministry of Forests.

Thanks are extended to members of the Karst Management Working Group for their valuable input into the development of the karst best management practices, and for reviewing numerous drafts of the handbook (in alphabetical order): Hugh Bomford (Canadian Forest Products Limited), Peter Bradford (Forest Practices Branch), Cam Brady (Port McNeill Forest District), Steve Chatwin (Research Branch), Charlie Cornfield (Campbell River Forest District), Bob Craven (Doman-Western Forest Products Limited), Stu Ellis (Canadian Forest Products Limited), Gerry Fraser (Doman-Western Forests Products Limited), Laura Friis (Ministry of Water, Land and Air Protection), Paul Griffiths (Cave Management Services), Doug Herchmer (Vancouver Forest Region), Dan Hogan (Research Branch), Bill I'Anson (Writer, Researcher), Bill Marshall (Forest Practices Branch), Teresa Morris (Ministry of Energy and Mines), Hal Reveley (Vancouver Forest Region), Gerry Still (Research Branch), and Tim Stokes (Terra Firma Geoscience Services).

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Thanks also to Kevin Kiernan (Forest Practices Board, Tasmania) for reviewing the initial draft of the handbook, and to Jim Baichtal (US Forest Service, Tongass National Forest, Alaska) and Tom Aley (Ozark Underground Laboratory, Missouri) for their review of various sections of the handbook.

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Finally, Paul Griffiths and Bill I'Anson must be singled out for their significant contributions to this project.

Layout and design by TM Communications Inc.

Ralph Archibald
Director, Forest Practices Branch

Table of Contents

Figures

Tables

I. Introduction

Karst management in British Columbia has traditionally focused on the management of caves, particularly with regard to recreational use. In recent years, however, the focus has expanded to consider the entire karst ecosystem—both surface and subsurface components. Karst is now recognized as a valuable, non-renewable resource that can be highly sensitive to disturbance.

In response to increasing concerns over the impacts of forestry on karst terrain in British Columbia, the Chief Forester initiated the development of this handbook for forest operations on karst. The intent of the handbook is to recommend best management practices for protecting natural karst systems and processes, while integrating the management of karst resources with the management of forest lands.

The recommended best management practices in this handbook are designed to effectively manage both surface and subsurface karst resources, primarily through appropriate management activities on the surface. For recommendations related to recreation management of surface karst features and caves, refer to the *Cave/Karst Management Handbook for the Vancouver Forest Region* (B.C. Min. For. 1994) or the *Ministry of Forests Recreation Manual*, Chapter 13, Cave/Karst Management (B.C. Min. For. 1991).

II. General Karst Information

What is Karst?

Karst is a distinctive topography that develops as a result of the dissolving action of water on soluble bedrock (usually limestone, dolomite, marble and, to a lesser extent, gypsum), which produces a landscape characterized by fluted and pitted rock surfaces, vertical shafts, sinkholes, sinking streams, springs, subsurface drainage systems, and caves. The unique features and three-dimensional nature of karst landscapes result from a complex interplay between geology, climate, topography, hydrology, and biological factors over long time scales. (For an illustrated glossary of various karst features, refer to Appendix I.)

How Karst is Formed

The formation of karst in carbonate bedrock involves what is referred to as "the carbon dioxide (CO_2) cascade" (see Figure 1). As rain falls through the atmosphere, it picks up CO_2, which dissolves in the droplets. Once the rain hits the ground, it percolates through the soil and picks up more CO_2 to form a weak solution of carbonic acid: $H_2O + CO_2 = H_2CO_3$. The infiltrating water naturally exploits any existing joints or fractures in the bedrock. With a continuous supply of CO_2 enriched water, the carbonate rock begins to dissolve, creating larger openings for the water to follow.[1] This process, occurring over many thousands of years, eventually leads to the development of underground drainage systems and caves.

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[1] The mechanical erosion of running water and rock fragments also contributes to the formation of karst.

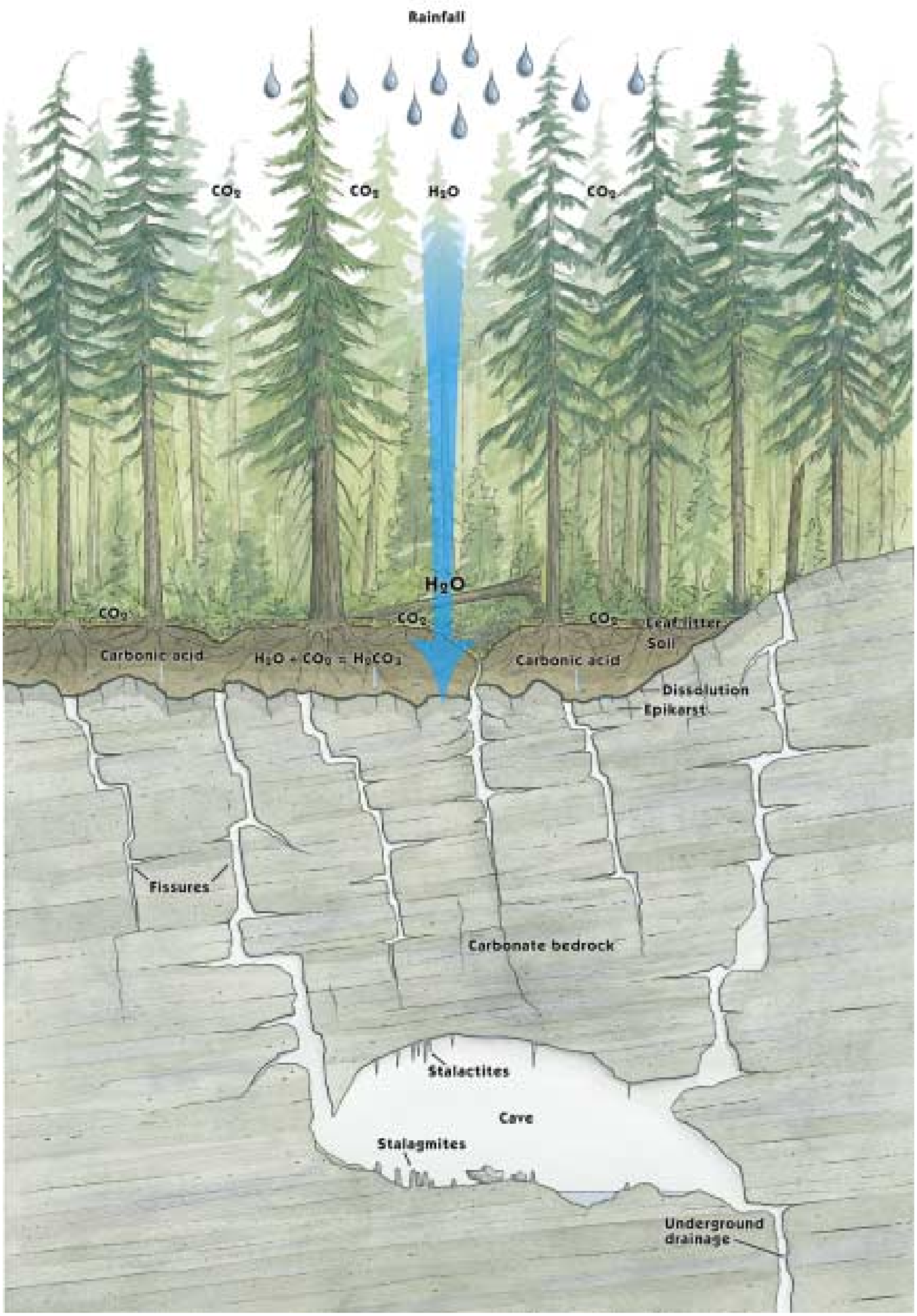


Figure 1. The carbon dioxide cascade.

Distribution of Karst in British Columbia

Carbonate bedrock, or formations containing carbonates, underlie approximately 10% of British Columbia, providing an extensive area for potential karst development (see Figure 2). The level of karst development across the province is highly variable, and depends on a number of different attributes, such as bedrock type and purity, physiographic location, and biogeoclimatic setting.

Figure 2. Approximate distribution of carbonate bedrock in British Columbia.

Glaciation has played a major role in the karst formation process in British Columbia by exposing, eroding and burying earlier developed karst. The extensive glacial deposits commonly associated with the interior of the province likely mask significant areas of buried karst terrain, where the karst is generally only exposed in alpine or sub-alpine locations.

Karst occurs in all of British Columbia's forest regions. Extensive areas of alpine karst occur in the Rocky Mountains, particularly in the south. Well-developed and highly significant karst areas associated with temperate rainforest occur in less extensive carbonate units on Vancouver Island and the Queen Charlotte Islands. Smaller, isolated areas of forested karst are known along the North Coast (e.g., Chapple Inlet) and near Chilliwack. In the Purcell Mountains, karst has developed in narrow, steep bands of limestone and marble (e.g., Nakimu Caves in Glacier National Park). Other, less well-known areas of karst, are reported in Northwest B.C. (e.g., along the Stikine and Taku Rivers), Northeast B.C. (e.g., near Chetwynd and Prince George), and in the Interior (e.g., near Williams Lake and in the Nelson area). A number of small gypsum karst sites are located at Canal Flats in the southeast of the province and in the Tatshenshini in the northwest.

Much of the karst in British Columbia is comparable to karst terrain in other parts of the world. The alpine karst in the Rocky Mountains is similar to that found in the European Alps and the Pyrenees. Karst in the Purcell Mountains is similar to the "stripe karst" of Arctic Norway. The karst in the interior plateau of the province is least known, but appears to be similar to that of the southern slopes and foothills of the Julian Alps in Slovenia.

Timber harvesting concerns in British Columbia have mainly focused on the karst on Vancouver Island, the Queen Charlotte Islands, and along the mainland coast. These karst areas are comparable to those of the Alaska Panhandle, portions of Patagonia (Chile), Tasmania, and the west coast of the South Island of New Zealand. All of these areas have very steep surface slopes and subsurface hydraulic gradients, with high levels of rainfall. These characteristics place British Columbia's coastal karst among the most dynamic on earth, evolving and changing more rapidly than karst in more moderate settings.

Importance of Karst

Karst is a unique, non-renewable resource with significant biological, hydrological, mineralogical, scientific, cultural, recreational, and economic values.

Biological Values

Forest productivity – Based on research from Vancouver Island and Southeast Alaska, coastal forest karst ecosystems are commonly more productive than similar forest sites on non-karst terrain. This increased productivity can be largely attributed to the well-drained soils and nutrient cycling associated with karst. As carbonate bedrock is dissolved by penetrating water, it releases CO_2, calcium carbonate, and micro-nutrients into the soil which help encourage the growth and development of trees and other plants. Plants are able to root exceptionally deep into karstified bedrock by following solutionally enlarged fractures. In some instances, tree roots have been observed penetrating through the roofs of caves located 30 metres or more below the surface.

Coastal forest karst ecosystems are often characterized by large mature trees, diverse plant and animal communities, highly productive aquatic systems, well-developed underground drainage, and extensive surface and subsurface karst resources. Because of the desirable qualities of the trees, harvesting in these areas has been extensive, particularly in the valley bottoms and at lower elevations.

Coastal forest karst ecosystem

While forested karst areas in the Interior are not currently well understood, it is reasonable to assume that they are also areas of locally enhanced productivity.

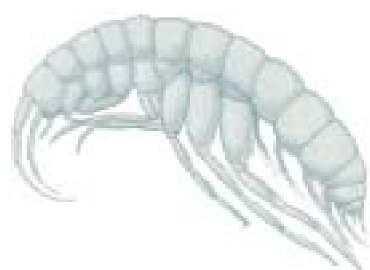
Unique plant and animal habitat – Karst ecosystems often support unusual or rare plant and animal species, both on the surface and underground. For example, certain species of ferns and mosses prefer or, in some cases, require a limestone substrate on which to grow. Other fern species have adapted to growing in the cool, moist twilight conditions of cave entrances.

Ferns in cave entrance

Many wildlife species use various karst features for habitat. Caves are used intermittently by large carnivores for shelter or resting. Birds and small mammals, such as woodrats, often nest in caves and other cavities. Elk and deer commonly bed down in the vicinity of cave entrances during summer when the air from caves is cooler, and during the winter when cave air is generally warmer than surrounding temperatures. Caves, and their stable environments, can be critically important habitat for bat species that depend on them for roosting and hibernation.

Keen's bat

Some karst-dependent species, known as troglobites, have evolved over time to live exclusively in the total darkness and stable temperatures of underground environments. Many troglobitic species are remnant invertebrates that survived the last ice age in subsurface cavities and caves. These organisms are totally dependent on underground microclimates and habitats, and represent important links to life forms from the past. An example of a known troglobite in British Columbia is the rare freshwater crustacean *Stygobromus quatsinensis* found in underground pools in caves on Vancouver Island.



Stygobromus quatsinensis

Cave cricket

Much more common are troglophiles, which are species capable of living both above and below ground. Some individual troglophiles may complete their entire life cycle underground, while other members of the same species live on the surface. Examples of troglophiles in British Columbia include some species of salamanders, spiders, and crickets.

Trogloxenes are animals that use caves for specific purposes, but do not live their entire lives in caves. Bats are good examples of trogloxenes.

Troglobites, troglophiles, and trogloxenes can all be highly susceptible to even minor disturbances in their environment.

Fisheries – Research in southeast Alaska indicates that karst can increase fish productivity in the following ways:

- the leaching of calcium carbonate from carbonate bedrock has important buffering effects on acidic streams;
- the groundwater associated with karst results in cool, even stream temperatures throughout the year;
- the storage capacity in some karst stream systems can buffer seasonal flow rates to produce lower peak flows and higher low flow periods;
- karst streams tend to supply more nutrients and encourage more algae and moss growth;
- aquatic insect populations within karst streams are larger and more diverse; and
- karst stream systems can provide more sites for fish to rest, breed, and avoid predators.

Adult coho salmon in Vancouver Island cave

Hydrological Values

Water quality and quantity issues play an important role in karst terrain. The subsurface drainage networks associated with karst add a vertical underground dimension that can be difficult to define and understand. These underground hydrological systems can operate independently from the overlying surface drainage patterns, and sometimes cross topographic drainage divides. They are also capable of moving large quantities of water over great distances in relatively short periods of time.

The rapid transit times and limited natural cleansing and filtering mechanisms associated with subsurface stream systems can readily transport harmful materials, such as contaminants or sediments, from one area to another. These materials have the potential to seriously impact sensitive karst environments (e.g., surface and subsurface habitats, cave formations, and other secondary deposits), associated aquatic communities, and human water supplies. Variations in water quantity outside the range of natural conditions can alter both diffuse and discrete groundwater recharge rates to impact ongoing karst processes within the overall karst ecosystem.

Stream sinking into swallet

Mineralogical Values

Mineral deposits within karst cave systems can be quite extensive and come in a variety of forms, depending on the host bedrock and a number of other environmental conditions. Many of these formations add significantly to the recreational value of caves (e.g., stalactites, stalagmites, moon milk, cave pearls).

Cave pearls

Some of the more pure carbonate bedrocks in British Columbia have long been recognized for their commodity values (see Economic Values). Carbonate bedrock can also be a favourable environment for ore deposits, and oil and gas exploration.

Scientific Values

Karst landscapes offer a great wealth of scientific and educational opportunities. Subsurface karst environments, in particular, can provide a relatively undisturbed window into landform evolution and past environmental conditions. Data on climate change can be obtained through the study of cave morphology and secondary deposits, such as speleothems and sediments.

The natural environment of karst caves—alkaline conditions, cool temperatures, the absence of light, and difficult access—provide good opportunities for the discovery of undisturbed archaeological materials and well-preserved animal remains. Information obtained from these kinds of sites can help reveal details of how ancient peoples lived, provide evolutionary links to the past, and help determine historic and prehistoric human and animal migration patterns.

11,000-year-old black bear bones in a Queen Charlotte Island cave

Most of the known cultural (stone tools) and anatomical (bone) remains of *Homo neanderthalensis* and early *Homo sapiens* are from limestone caves. Caves in the United States host the earliest remains of humans in the Western Hemisphere.

Cultural Values

In the past, karst played a significant role in the lives of many aboriginal peoples living on the west coast. Caves were often used for shelter, burial sites, and ceremonial purposes.

Cave pictograph

Unusual surface karst features commonly played a role in aboriginal culture, and the water from karst springs was viewed as having special properties. In many cases, the productivity of karst landscapes benefited aboriginal peoples by supplying large trees for dugouts, construction materials, or totem poles, and by providing excellent growing sites for various shrubs and herbs used for food and medicines.

Many present-day aboriginal cultures continue to value karst for ancestral, heritage, and cultural reasons.

Recreational Values

The globally significant karst areas of British Columbia attract recreationists and caving enthusiasts from around the world. The extensive karst systems in the Rocky Mountains and on Vancouver Island are particularly popular viewing and cave exploration areas.

Each year, increasing numbers of people visit British Columbia's provincial forests, parks, and recreation areas for self-guided or commercially guided karst and cave experiences.

Recreational caver

Economic Values

The economic values associated with karst in British Columbia are considerable. One of the primary economic benefits is the harvesting of high-value timber resources on productive karst landscapes, particularly on Vancouver Island. Agricultural lands overlying karst are also typically very productive because their soils are richer in lime.

The attractive recreation value found in many karst areas (surface karst features, underlying caves, high biodiversity) generates employment and revenue in tourism-related industries throughout the province.

Limestone and dolomite extraction provides a number of raw materials and processed products for agriculture; glass and paint manufacturing; and the concrete, pulp and paper, and construction industries. Limestone, dolomite, and marble are also commonly used in buildings and for ornamental stone.

Limestone pit on Texada Island

III. Karst Management Strategy

The three-dimensional nature of karst causes it to function quite differently from other landforms, and presents unique challenges to land management. In particular, the potential for karst hydrological systems to transport air, water, nutrients, soil, and pollutants into and through underground environments should be carefully considered when developing and implementing management strategies for karst landscapes.

One of the key elements to karst management is acknowledging the importance of karst as a complex ecosystem, and focusing efforts on protecting the integrity of karst systems as well as individual karst features. As such, karst terrain should be carefully inventoried and assessed for its vulnerability to proposed land uses.

The primary goal of the *Karst Management Handbook for British Columbia* is to provide recommendations for protecting natural karst systems and processes, while integrating the management of karst resources with the management of forest lands. This includes managing subsurface karst resources through appropriate forest management practices applied on the surface karst environment.

The recommended best management practices in this handbook are designed to promote sustainable forest practices on karst landscapes and achieve the following objectives, while minimizing impacts to timber supply and operational costs:

- maintain the capability of karst landscapes to regenerate healthy and productive forests after harvesting;
- maintain the high level of biodiversity associated with karst ecosystems, including surface and subsurface habitats;
- maintain the natural flows and water quality of karst hydrological systems;
- maintain the natural rates of air exchange between the surface and subsurface;
- manage and protect significant surface karst features (e.g., sinkholes, sinking streams, springs, and cave entrances) and subsurface karst resources (e.g., caves, underground streams, and subterranean fauna); and
- provide recreational opportunities where appropriate.

IV. Karst Inventories and Vulnerability Assessments

British Columbia's Karst Inventory System

The integration of karst management with forest development relies on an inventory process that accurately identifies areas of karst terrain, and assesses the inherent vulnerability of the karst system in those areas. This information can then be used to apply appropriate forest management practices to specific karst areas, depending on their level of vulnerability.

A set of standards and procedures for completing karst inventories and vulnerability assessments are described in *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003). The RISC document outlines three levels of karst inventories:

- reconnaissance level (1:250 000 scale);
- planning level (e.g., 1:20 000 or 1:50 000 scale); and
- karst field assessments (e.g., 1:5000 or 1:10 000 scales).

These three levels of inventory provide a filtered approach to evaluating karst terrain—beginning at the broad reconnaissance level and progressing through an intermediate planning level to the more detailed karst field assessment. Each level has increasing requirements for data collection and evaluation, and provides valuable information for forest management planning.

Reconnaissance-level Karst Inventories

Reconnaissance-level karst inventories are used to identify areas of potential karst development at a regional (1:250 000) scale. This information can be used to assist with strategic planning (e.g., higher level plans, land-use plans, TFL management plans), and to help direct planning-level inventories or karst field assessments.

Reconnaissance-level karst inventories have been completed for the entire province of British Columbia, resulting in a set of 87 NTS 1:250 000 karst potential maps.[2]

Planning-level Karst Inventories

Planning-level karst inventories are carried out at the 1:20 000 or 1:50 000 scale to obtain a general sense of the types and distribution of karst attributes over a landscape or watershed. This level of inventory can be particularly helpful if a series of roads and cutblocks are anticipated over a large, well-developed karst unit. Due to the complexity and high level of knowledge and expertise required

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2 Reconnaissance-level karst potential maps are available in digital format at: ftp://ftp.for.gov.bc.ca/branches/research/external/!publish/karst/.

to conduct planning-level karst inventories, this type of inventory should be carried out by experienced professionals.

A planning-level inventory could be triggered under the following circumstances:

- reconnaissance-level karst potential maps indicate that an area of proposed development may be underlain by karst;
- there is previous knowledge of karst in or around an area of proposed development; or
- karst features have been identified on the ground in or around an area of proposed development.

Data from planning-level inventories can readily be used to delineate the boundaries of a karst unit, and determine the distribution and variation in karst development over a landscape. This information can be useful for identifying operable areas within a TFL and for estimating net down areas due to karst terrain.

Another application of planning-level karst inventories is the identification of karst and non-karst catchment areas that may directly or indirectly impact downstream karst units. Planning-level inventories can also help direct karst field assessments by identifying significant surface karst features, sinking streams, springs, and other prominent karst features that may require further investigation at the site level.

Planning-level inventory data is used to stratify a karst unit into polygons of differing vulnerability potential. These vulnerability potential polygons provide a preliminary indication as to the scope and intensity of karst development within a particular area. Polygons mapped as moderate, high, or very high vulnerability potential should have a karst field assessment completed prior to the initiation of forestry activities to accurately delineate the characteristics of the karst. Low vulnerability potential polygons would likely only require a cursory level of field verification to confirm the expected low level of karst development.

Karst Field Assessments

Karst field assessments are conducted at the 1:5000 or 1:10 000 scale to evaluate karst attributes within a relatively small area of interest (e.g., proposed cutblock or road). These detailed assessments are recommended prior to road construction or forest harvesting on karst terrain, and should typically be carried out prior to or during the development of site-level plans. Karst field assessments should be carried out by personnel who have successfully completed the RISC *Karst Field Assessments Training Course* (RISC 2003).

A karst field assessment could be triggered under the following circumstances:

- an area of proposed development is underlain by carbonate bedrock;
- an area of proposed development is planned on non-carbonate lands located within the contributing drainage basin of known or suspected carbonate units;[3]

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[3] In this case, the karst field assessment would be carried out on the known or suspected karst units located downstream of the proposed development.

- reconnaissance-level karst potential maps indicate that a proposed development may be underlain by karst;
- a planning-level inventory has identified karst polygons with moderate, high, or very high vulnerability potential ratings in or around an area of proposed development;
- there is previous knowledge of karst in or around an area of proposed development;
- karst features have been identified on the ground in or around an area of proposed development; or
- forestry activities, such as windthrow salvage, spacing, pruning, or commercial thinning, are planned on an area known or suspected to be underlain by carbonate bedrock.

Karst field assessments are primarily surface karst inventories, but can also include subsurface evaluations if caves are encountered. Field activities include:

- locating, classifying, and determining the significance of surface karst features;
- estimating epikarst development and soil thickness;
- estimating the density of surface karst features;
- evaluating karst roughness;
- assessing streams;
- inspecting and mapping caves where encountered;
- estimating subsurface karst potential;
- identifying unique or unusual flora/fauna and/or habitats; and
- identifying potential geomorphic hazards that could impact the karst unit.

Specific field procedures for karst field assessments are described in detail in *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003).

The data collected during a karst field assessment are used to stratify the karst area of interest into polygons of similar karst attributes and vulnerability. These data also identify 'significant' surface karst features where specific protective measures (e.g., reserves) are recommended for forest operations. Stream assessments conducted during a karst field assessment identify sinking and losing streams/sinking watercourses where special riparian management considerations are recommended.

Assessing the Vulnerability of the Karst Landscape

Karst vulnerability is determined using a systematic procedure that evaluates three major criteria: epikarst sensitivity, surface karst sensitivity, and subsurface karst potential. Other factors considered in assessing vulnerability include soil texture, overall karst roughness, and unique or unusual flora/fauna or habitats. Using this procedure, vulnerability ratings can be determined for each karst polygon—low, moderate, high, or very high. These ratings are used to guide appropriate forest management practices for the karst area within each polygon based on the assessed level of vulnerability (see Section VIII).

The procedure for determining karst vulnerability is fully described in *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003). Descriptions of the four possible karst vulnerability classes are provided in Appendix II.

Assessing the Significance of Karst Features

Determining the 'significance' of surface karst features and caves is another important task of a karst field assessment. This process involves a qualitative evaluation of a number of criteria (see Figure 3).

For surface karst features, these criteria can include:

- dimensional characteristics;
- the level of connectivity between the surface and subsurface;
- hydrological characteristics;
- geological values;
- biological values;
- scientific and educational values;
- archaeological, cultural and historical values;
- recreational and commercial values;
- rarity and abundance; and
- visual quality.

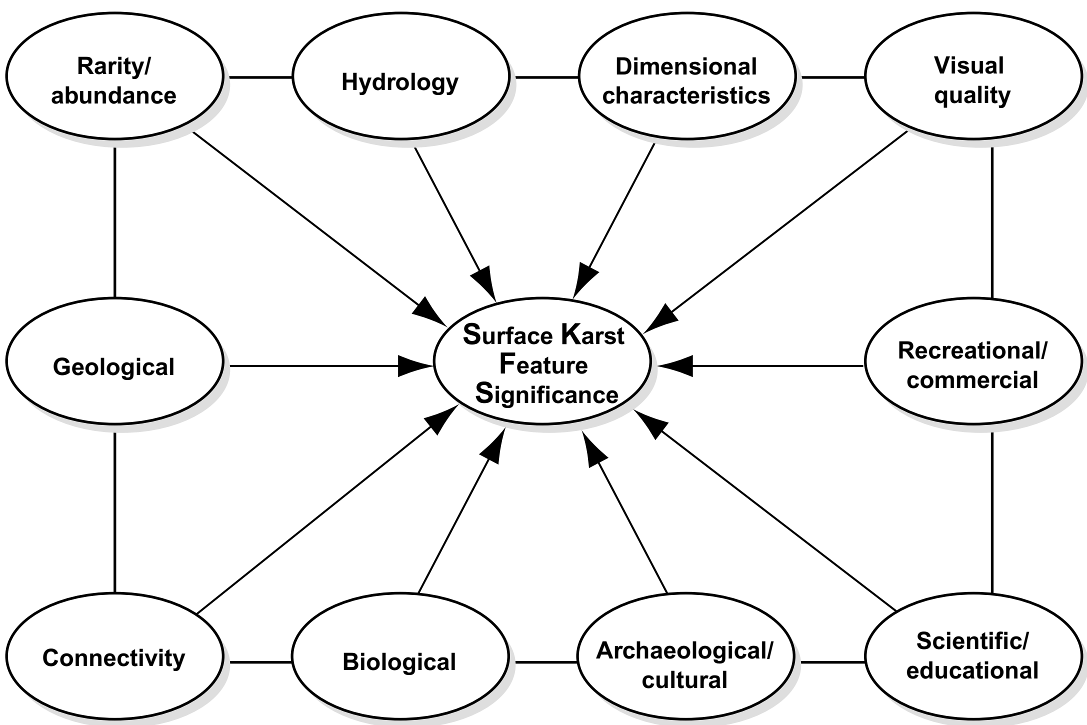

Figure 3. Significance of karst features.

Examples of significant surface karst features might include a sinkhole of sufficient size to support a localized microclimate, a spring associated with unique flora or fauna, or a visually attractive rock arch formation.

Determining the significance of caves involves subsurface inspection and mapping, which should only be conducted by personnel with specialized knowledge, training and experience. Significant caves might include:

- well-developed decorations;
- significant hydrological, archaeological, paleontological, or cultural values;
- bat hibernacula or rare cave-dwelling organisms;
- scientifically important climatological or geomorphological sediments;
- significant recreational opportunities; or
- unique intrinsic values, such as large dimensions, unusual configuration, and rare/uncommon location.

Detailed procedures for determining the significance of surface karst features are described in *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003). Guidance for the inspection and classification of caves is provided in the *Cave/Karst Management Handbook for the Vancouver Forest Region* (B.C. Min. For. 1994).

Assessing Streams/Watercourses

During a karst field assessment, streams/watercourses are assessed to see if they sink or lose water to the subsurface, as these have the potential to transport sediment, organic material, and woody debris into underground karst environments. The significance of the karst resources receiving the water (recipient karst features) is also assessed. Procedures for assessing streams/watercourses and determining the significance of recipient karst features are described in *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003).

Karst Inventory Information Management

Inventory information on the location of sensitive or hazardous surface karst features and caves should be kept confidential until appropriate measures for managing the resource feature have been developed in consultation with appropriate agencies (e.g., Ministry of Forests, Ministry of Sustainable Resource Management).

V. Applying the Karst Best Management Practices

The best management practices recommended in this handbook are designed to be used in conjunction with the results of a karst field assessment. Recommended practices are provided for both the broad karst landscape and specific karst features. While many of the recommended practices focus on the management of individual karst features, collectively, these practices will serve to provide protection for the whole karst ecosystem.

Section VI recommends best management practices for significant karst features. Section VII provides riparian management recommendations for sinking and losing streams/sinking watercourses. Section VIII recommends best management practices for road building, timber harvesting, and post-harvest operations broken down by vulnerability category. Section IX addresses management strategies for the non-karst portions of karst catchment areas.

VI. Significant Karst Features

Significant karst features are identified by their higher relative values as determined by the process described in Section IV and *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003). To protect these higher values, reserves are recommended for the following:

1. significant cave entrances;
2. above significant caves (depending on depth);
3. significant surface karst features;
4. significant karst springs; and
5. unique or unusual karst flora/fauna habitats.

Where the significance of a karst feature is unknown, or has not been determined, it is recommended that the feature be treated as significant until a significance determination can be made.

> Whenever possible, consider the potential for combining existing retention strategies/requirements (e.g., the retention silvicultural system, old-growth management areas, riparian management areas, wildlife tree retention, and wildlife habitat areas) with the establishment of protective measures for karst.

Important Note

The suggested reserve sizes for significant karst features and values in this section are default recommendations. However, local site conditions (e.g., windthrow risk) should be carefully considered during the planning of reserve size and shape.

The planning and design of all karst reserves should be based on a thorough windthrow assessment.[4] If the default karst reserve recommendations cannot be maintained due to severe windthrow potential, professional judgement should be used to develop site-specific management practices that achieve as many of the management objectives for the reserve as possible.

In addition, the default recommendations for reserve size are based on relatively flat terrain. Where features occur on slopes, there may be a need to alter the shape and size of the reserve and/or management zone. On steep slopes, this could involve extending the reserve and/or management zone on the upslope side of features (e.g., sinkholes) to account for the increased risk of slumping and soil erosion (see Figure 4).

On slopes, reserve and management zone widths should be measured using slope distance.

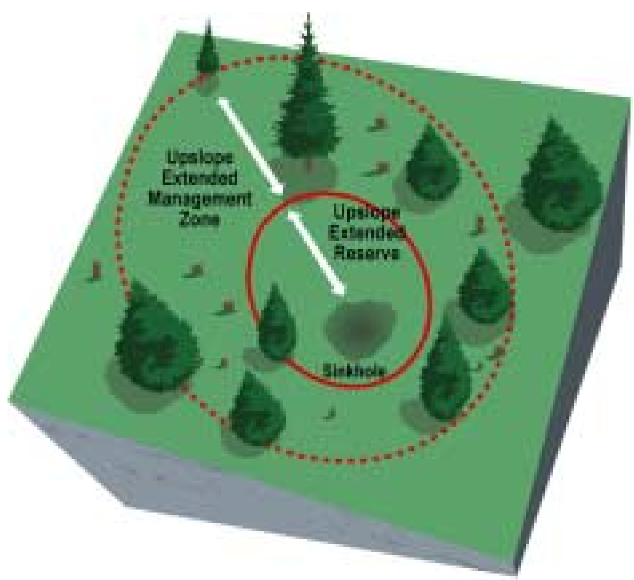

Figure 4. Extending reserves and management zones on steep slopes.

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[4] For direction in assessing windthrow risk, consult the *Windthrow Handbook for British Columbia Forests* (Research Program Working Paper 9401) at: http://www.for.gov.bc.ca/HFP/FORDEV/windthrow/index.htm
Windthrow Assessment Field Cards (FS712 – 1, 2,3,4 HFP98/05) are available at: http://www.for.gov.bc.ca/pscripts/isb/forms/forms.asp

1. Significant Cave Entrances

Management Objectives

- To maintain the microclimate around significant cave entrances to ensure water flow, air flow, air temperature, relative humidity, and level of shading remain constant so as not to alter conditions for air and water exchange, subsurface habitats (e.g., bats, invertebrates), cave formation processes, etc. beyond the range of natural variability.
- To maintain stable habitat conditions for flora inhabiting the cave entrance and/or cave dwelling organisms (e.g., spiders, crickets, salamanders) that forage in the cave entrance or rely on organic matter from the cave entrance falling into the cave as a food source.
- To prevent logging debris from entering significant cave entrances.
- To provide a measure of aesthetics/recreational experience for cave entrances with high recreation values.

Best Management Practices

The following best management practices are recommended:

- A minimum two-tree-length reserve (based on the average height of the dominant and co-dominant trees at 100 years) extending outward from the mouth of the cave entrance. In the case of a significant entrance contained within a sinkhole, the reserve should extend from the rim or edge of the sinkhole, as defined by the upper break of the slope enclosing the sinkhole.
- An adjacent management zone of an appropriate size to protect the reserve from windthrow (see Important Note, page 21). (See Figure 5.)
- To help maintain interior microclimatic conditions and inhibit the encroachment of edge species into the interior habitat of the reserve, retain understorey vegetation along reserve boundaries and leave some green trees in the adjacent opening, especially near the edge of the reserve.
- Follow the recommendations in *Managing Identified Wildlife: Procedures and Measures* (Prov. B.C. 1999)[5] for reserves around the entrance of caves known to contain bat hibernacula for red- or blue-listed species (e.g., Keen's long-eared myotis).

> It is recommended that entrances possessing none of the criteria for a significant cave entrance be managed with a 20-metre management zone around the entrance using the following practices:
>
> - fall and yard away from the cave entrance as much as possible;
> - remove any slash and debris that falls in or around the cave entrance, provided removal does not cause further disturbance; and
> - retain windfirm non-merchantable trees, advanced regeneration, wildlife trees, and other windfirm vegetation within the management zone.

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[5] The *Managing Identified Wildlife: Procedures and Measures* web site is located at: http://wlapwww.gov.bc.ca/wld/identified/species_table_of_contents.htm

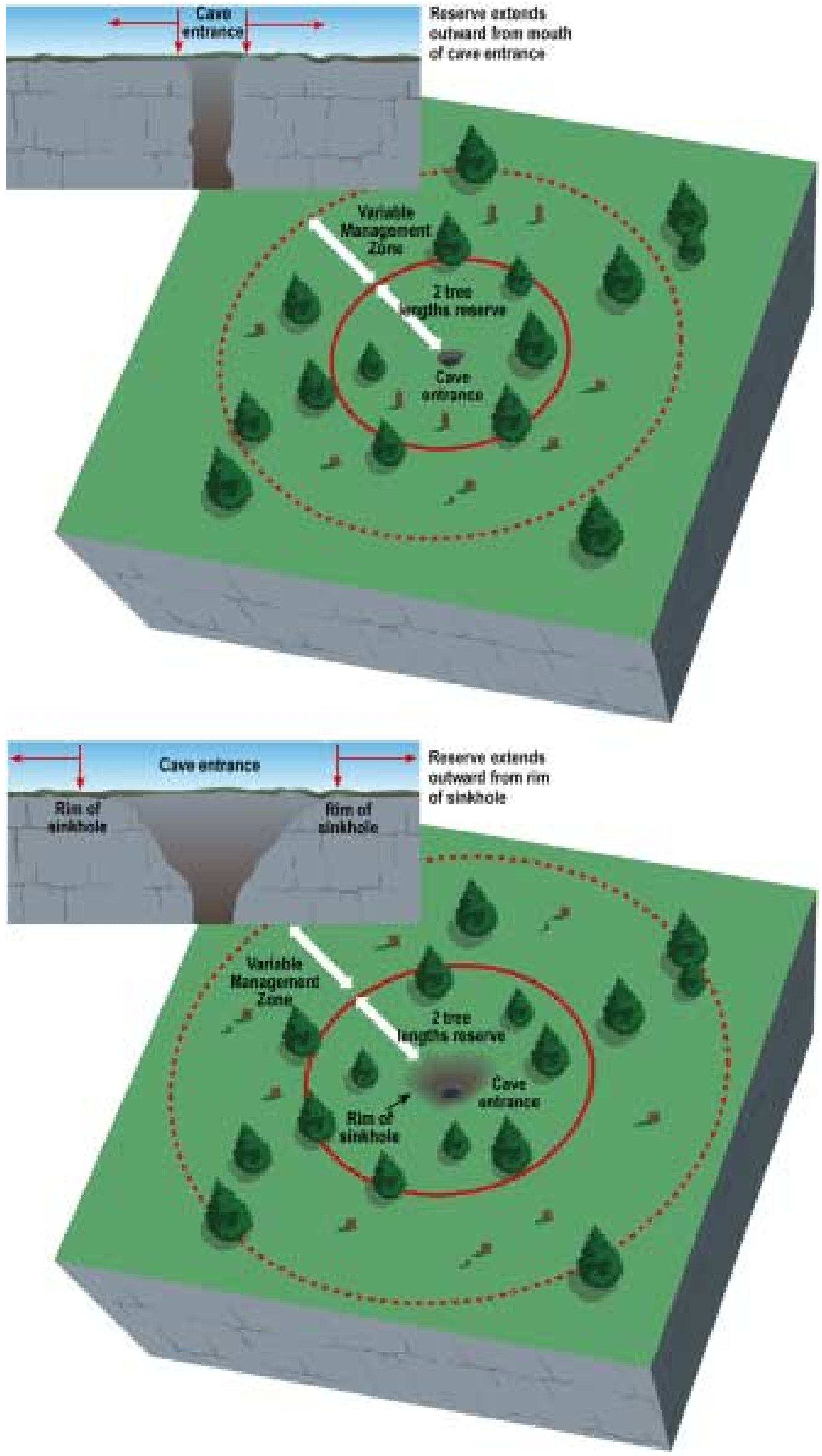

Figure 5. Reserves and management zones around significant cave entrances.

2. Above Significant Caves

Management Objectives

- To maintain stable conditions for karst processes above and within significant caves (e.g., temperature, humidity, infiltration rates, and drip water chemistry).
- To prevent the migration of surface fines/sediment into significant caves through fissures or cavities in the overlying epikarst.
- To protect delicate cave features, cave fauna, or other cave values from potentially damaging vibrations associated with road construction and timber harvesting.

Best Management Practices

The following best management practices are recommended:

- Establish reserves, and management zones of an appropriate size to protect the reserves from windthrow, above significant caves situated less than three times the greatest dimension (height or width) of the cave passage below the surface of the ground (Derek Ford, pers. comm., December 1999). (See Important Note, page 21.) This recommendation is based on the principle that the cave is primarily influenced by diffuse percolation from within a 45-degree angle on either side of the outside wall of the cave passage. The size and shape of the reserve can be projected to the surface using cave maps. The reserve generally only applies where the cave ceiling lies less than three times the greatest dimension (height or width) of the cave passage below the surface of the ground; where the cave ceiling lies below this depth, harvesting should be able to occur safely in most instances. However, some shallow, significant caves with relatively small dimensions may not be adequately protected using the 3× depth criteria. For example, a significant cave with a 2-metre passage (height or width) situated 8 metres below the surface would not qualify for a reserve using the 3× depth criteria. To minimize risks to these types of significant caves, and to provide them with an adequate level of protection, a minimum depth rule should be applied. Significant caves situated less than 10 metres below the surface should receive a reserve in all cases, regardless of whether the cave meets the 3× depth criteria or not.
- Significant caves that are deeper than three times the greatest dimension (height or width) of the passage below the surface, but are known to contain *exceptional* features or values (e.g., highly unique/rare/unusual), should receive special consideration. Specialized harvesting practices may need to be considered to ensure the contents of these types of caves are protected. These specialized practices could include partial cutting, maximum/full suspension yarding to minimize soil disturbance, and leaving more coarse woody debris and non-merchantable vegetation to maintain soil humidity. The size of the management area for specialized harvesting practices should be projected to the surface using the 45-degree principle. (See Figure 6 for various scenarios for reserves above significant caves.) If the depth of soil likely to remain intact after harvesting is 0.5 metres or more, the use of partial cutting and maximum/full suspension yarding may not be necessary; however, retaining more coarse woody debris and non-merchantable

vegetation should be considered to help maintain soil humidity above the cave. [**Note:** The use of specialized harvesting practices above the cave would be in addition to any recommended measures for specific surface karst features within the same area.]

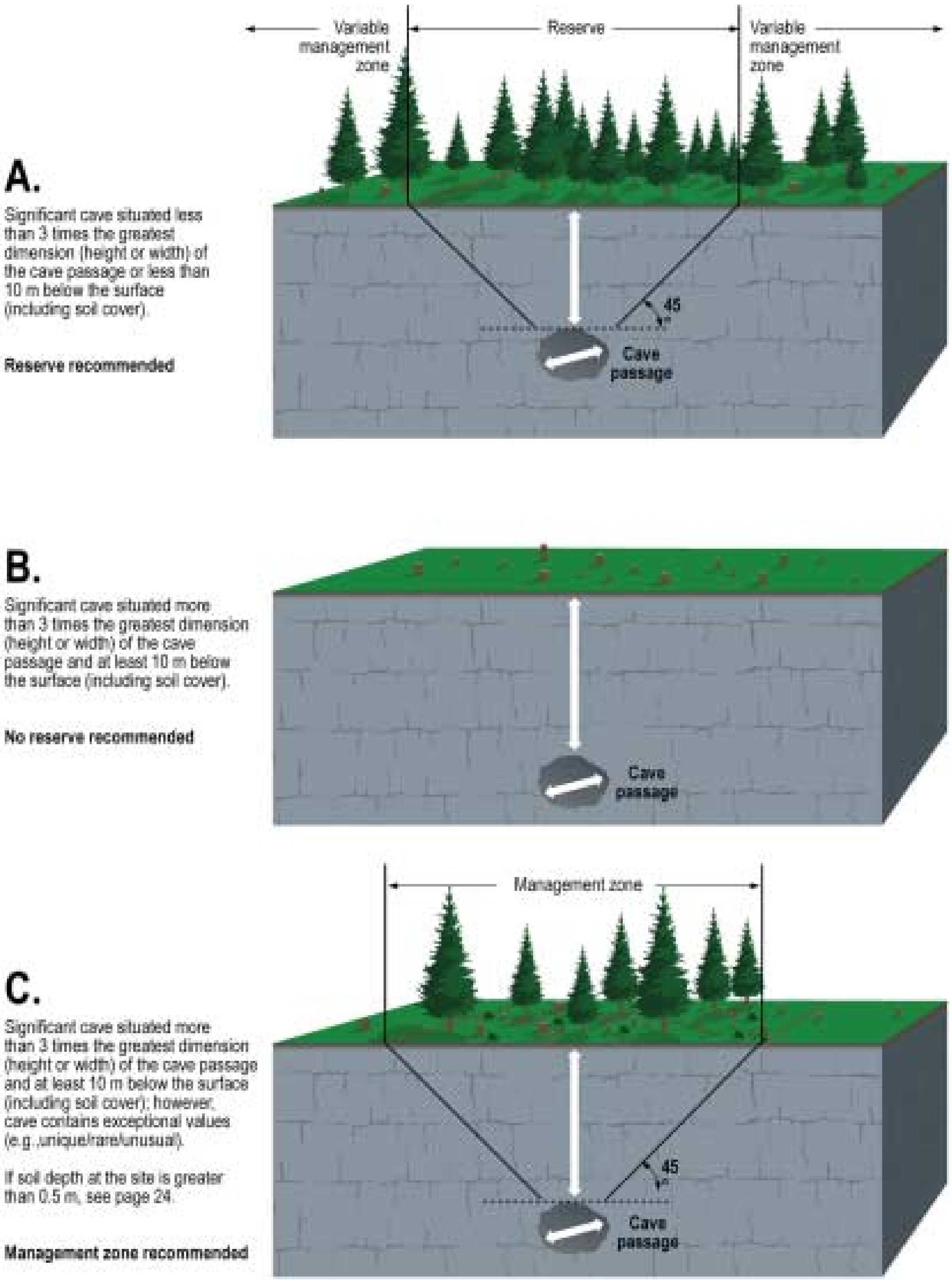

Figure 6. Scenarios for reserves and management zones above significant caves.

3. Significant Surface Karst Features

Management Objectives

- To protect significant surface karst features from physical damage.
- To maintain any site-specific microclimatic conditions and/or habitat/biodiversity characteristics associated with significant surface karst features.
- In the case of sinkholes, to prevent soil erosion and sediment transfer into subsurface openings or caves.
- To provide a measure of aesthetics/recreational experience for surface karst features with high recreation values.

Best Management Practices

The following best management practices are recommended:

- A minimum one-tree-length reserve (based on the average height of the dominant and co-dominant trees at 100 years) extending outward from the edge of the feature. For depression features, such as sinkholes, the edge of the feature should be considered the rim of the sinkhole, as defined by the upper break of the slope enclosing the sinkhole.
- An adjacent management zone of an appropriate size to protect the reserve from windthrow (see Important Note, page 21). (See Figure 7.)
- In cases where surface karst features have high recreation values, the reserve shape/size may need to be adjusted to manage for visual quality.
- Sinkholes large enough to create their own microclimate (i.e., support distinct vegetation with an obvious species gradient down the sideslope, or exhibit a distinctive temperature and relative humidity gradient), should be managed similarly to a significant cave entrance, with a reserve of two tree lengths to maintain interior microclimatic conditions. [**Note:** Large sinkholes are generally indicative of large subsurface cavities.] Sinkholes of this magnitude often support high biodiversity and habitat values.

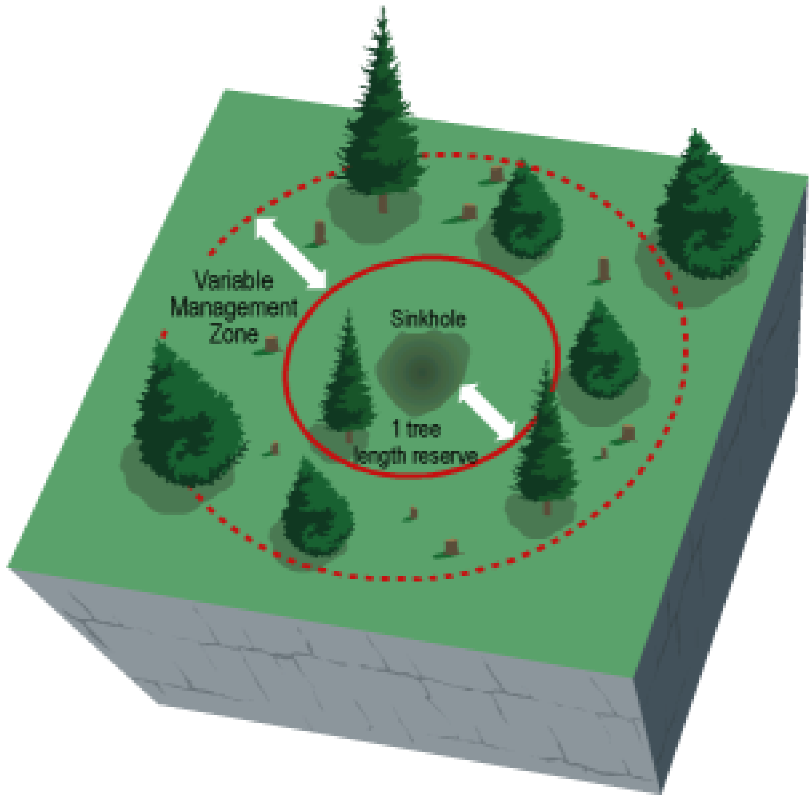

Figure 7. Reserves and management zones around significant surface karst features.

4. Significant Karst Springs

Management Objectives

- To maintain water quality and quantity (within the range of natural variability), wildlife habitat, and visual quality in cases where recreational values are identified.

Best Management Practices

The following best management practices are recommended:

- A minimum 20-metre reserve extending outward from the edge of the discharge point of the spring.
- An adjacent management zone of an appropriate size to protect the reserve from windthrow (see Important Note, page 21). (See Figure 8.)
- If the spring discharges into a stream channel, consult the default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act.*
- If the spring disperses into a wetland, consult the default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act.*
- Karst springs can be recharged by diffuse infiltration through contributing karst catchments, by surface runoff from sinking/losing streams flowing off

contributing non-karst catchments, or through a combination of the two. The level of activities in these recharge areas should be considered in the management of water quality and quantity for significant karst springs.

- Karst springs often create favourable environmental conditions (microclimates) and/or habitats for rare flora and fauna. Where unique or unusual species are encountered, the Conservation Data Centre should be notified for assistance in determining appropriate actions (e.g., providing additional protective measures if needed).[6]

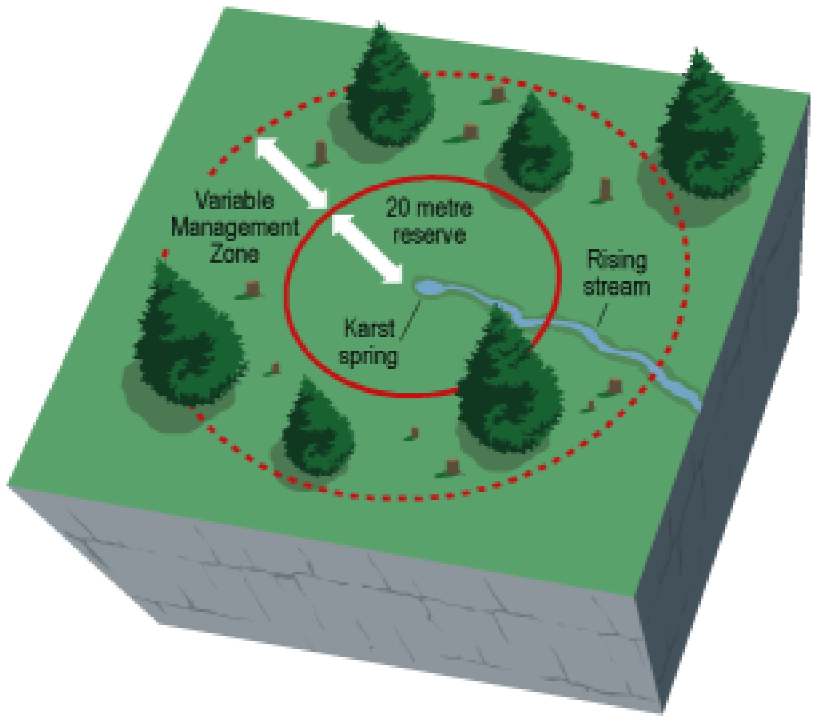

Figure 8. Reserves and management zones around karst springs.

[6] The Conservations Data Centre web site is located at: http://srmwww.gov.bc.ca/cdc/request.htm.

5. Unique or Unusual Karst Flora/Fauna Habitats

Management Objective

- To maintain potentially critical habitat for unique or unusual karst flora/fauna.

Best Management Practices

The following best management practices are recommended:

- Some plants, including some red- and blue-listed species of ferns and orchids, require or prefer a limestone substrate on which to grow. When unique or unusual plant communities are encountered on karst terrain, contact the Conservation Data Centre for assistance with identification and determining appropriate protective measures (see web site address in footnote #6).
- Most habitat requirements for karst-dependent fauna are addressed through reserves for significant caves, surface karst features, and karst springs. Nevertheless, when unique or unusual fauna are encountered on karst terrain, contact the Conservation Data Centre for assistance with identification and determining appropriate protective measures (see web site address in footnote #6).

Additional Recommendations for All Karst Reserves

- Roads and skid trails should not be located in karst reserves.
- Trees should not be felled within karst reserves except to remove safety hazards or to address forest health risks such as insect infestations. Where felling is required, consider using partial cutting, falling away from karst features, and leaving felled timber on the ground to provide coarse woody debris and an intact forest floor. If the felled timber must be removed, avoid yarding over or through karst features.
- Take measures to ensure that human wastes, petroleum products, herbicides, litter, and other pollutants do not contaminate karst reserves (i.e., follow proper storage and transport procedures).

VII. Riparian Management for Sinking and Losing Streams/Sinking Watercourses

On karst terrain, surface streams that do not sink or lose water to the subsurface can be managed using the default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act*. Streams/watercourses that sink or lose water to the subsurface may require special riparian management considerations, as they have the potential to transport sediment and debris into sensitive subsurface karst environments.

Since 1995, British Columbia has defined a "stream" as a watercourse with a continuous channel of more than 100 metres in length that exhibits evidence of scouring or alluvial deposition. While this definition can be applied to many of the surface streams flowing on karst terrain, some important watercourses that sink into the subsurface have the potential to be interpreted as non-classified drainages because they do not meet all the requirements of the definition for a stream (e.g., segments that fail to meet the 100-metre distance criteria). However, even though these types of watercourses do not meet the definition for a stream, they should still be recognized and managed appropriately in cases where they flow into significant recipient karst features. To account for this situation, and to avoid confusion with the accepted definition for a stream, watercourses of this type are referred to as "sinking watercourses."

This section describes management objectives and recommended best management practices for sinking and losing streams, and sinking watercourses.

Important Note

The processes involved with the movement of fine particulate matter in streams/watercourses flowing into subsurface karst openings is not well understood in British Columbia. Additional research into these processes is required. It is recommended that the management of sinking and losing streams, and sinking watercourses, be undertaken with an adaptive management approach, and that the process be modified and refined based on field experience and professional judgement.

Recommendations for riparian management should be considered the default option. As with karst reserves, local site conditions (e.g., windthrow risk) may not always allow the default recommendation to be achieved. If the default recommendations cannot be met, professional judgement should be used to develop site-specific practices that achieve as many of the management objectives as possible.

Sinking and Losing Streams

Sinking streams are streams that disappear underground at a distinct sink point (i.e., swallet). Losing streams are streams that gradually lose water through an unconsolidated alluvial channel bed, or through a series of indistinct small openings, fractures, or sink points. For the purpose of the *Karst Management Handbook for British Columbia*, 'losing streams' will only include those streams that lose water through small openings, fractures, or sink points, since the transfer of sediment and debris to the subsurface through water loss associated with unconsolidated alluvial channel beds will likely be negligible.

Some sinking and losing streams can spend a large part of the year as dry stream channels, only flowing when the subsurface karst system backs up and overflows during major storms or runoff events. When these types of streams flow, they can contribute major sources of sediment, organic material and other debris that are readily transported underground. On non-karst terrain, dry channels are generally not considered a major management concern; however, on karst, dry sinking or losing stream channels should be carefully considered for riparian management.

Management Objectives

(irrespective of whether the channels carry perennial, ephemeral, or intermittent flows)

- To maintain water quality and quantity, and to limit the introduction of sediment, fine organic material and woody debris into subsurface environments within the range of natural conditions.

  Rationale: Woody debris (large and small), sediment, and organic material can be transported downstream where it accumulates and clogs recipient karst features such as swallets or cave entrances. This can restrict water from entering the subsurface and/or redirect flows to other subsurface openings or to the surface. Of particular concern is the introduction of fine sediment (e.g., silts, sands, clays) and fine organic material (e.g., needles, twigs, leaves) into subsurface cavities, including caves. These materials can coat underground surfaces, thereby impacting subsurface habitats and other cave resources or values (e.g., mineral formations). The slow decay rate associated with underground environments in British Columbia allows the organic component of this material to accumulate and persist over long periods of time.

Best Management Practices

The following best management practices are recommended:

- Management recommendations for sinking and losing streams are provided in Tables 1, 2 and 3. The recommendations are based on stream width, which is considered an indicator of transport potential. Recommended minimum width thresholds are different for streams flowing on karst (1.0 m) compared to those flowing over non-karst (1.5 m). This is to account for the inherent sensitivity of karst to the transport of fine particulate matter into subsurface environments, and also considers the tendency of streams flowing over karst to incise into the soluble bedrock, creating somewhat deeper, narrower channels.

- Reserves and/or management zones along sinking or losing streams should completely encircle the recipient karst feature where the water flows underground.
- Sinking and losing streams are fed by surface runoff flowing off the contributing non-karst catchment area. The level of activity in the catchment area should be considered in the management of water quality and quantity for significant recipient karst features.

Table 1. Recommended best management practices for:
Sinking and losing streams <1.0 metre in width flowing on karst
Sinking and losing streams <1.5 metres in width flowing on non-karst

Results of Stream and Recipient Karst Feature Assessments	Recommended Best Management Practices within the Cutblock
1. Sinking or losing stream contributes water to a **significant** recipient karst feature located within 250 metres downstream of the cutblock boundary.	The following practices are recommended within an appropriately sized riparian management zone: • Retain windfirm trees with roots embedded in the bank. • Fall and yard away to the fullest extent possible. • Avoid cross-channel yarding. • Remove slash and debris that inadvertently enter the channel. • Retain windfirm non-merchantable trees and other windfirm vegetation (e.g., understorey, shrubs, herbs) within 5 metres of the channel. • Retain windfirm wildlife trees.
2. Sinking or losing stream contributes water to a **non-significant** recipient karst feature located within 250 metres downstream of the cutblock boundary. **OR** Sinking or losing stream contributes water to a known **significant** recipient karst feature located more than 250 metres downstream of the cutblock boundary. **OR** Stream does not sink or lose water within 250 metres downstream of the cutblock boundary.	Consult default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act*.
3. No stream assessment carried out.	Assume the stream contributes water to a **significant** recipient karst feature located within 250 metres downstream of the cutblock boundary. Treat the stream as per recommended management action in #1 above.
4. Stream assessment completed and recipient karst feature identified, but not assessed for significance.	Assume recipient karst feature is **significant**. Treat the stream as per recommended management action in #1 above.

Table 2. Recommended best management practices for:
Streams 1.0–3.0 metres in width flowing on karst
Streams 1.5–3.0 metres in width flowing on non-karst

Results of Stream and Recipient Karst Feature Assessments	Recommended Best Management Practices within the Cutblock*
1. Sinking or losing stream contributes water to a **significant** recipient karst feature located within 500 metres downstream of the cutblock boundary.	Establish a minimum 20-metre reserve along the stream, with an adjacent management zone of an appropriate size to protect the reserve from windthrow.**
2. Sinking or losing stream contributes water to a **significant** recipient karst feature known to be located more than 500 metres downstream of the cutblock boundary.	The following practices are recommended within an appropriately sized riparian management zone: • Retain windfirm trees with roots embedded in the bank. • Fall and yard away to the fullest extent possible. • Avoid cross-channel yarding. • Remove slash and debris that inadvertently enter the channel. • Retain windfirm non-merchantable trees and other windfirm vegetation (e.g., understorey, shrubs, herbs) within 5 metres of the channel. • Retain windfirm wildlife trees.
3. Sinking or losing stream contributes water to a **non-significant** recipient karst feature located within 500 metres downstream of the cutblock boundary. **OR** Stream does not sink or lose water within 500 metres downstream of the cutblock boundary.	Consult default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act*.
4. No stream assessment carried out.	Assume the stream contributes water to a **significant** recipient karst feature located within 500 metres downstream of the cutblock boundary. Establish a minimum 20-metre reserve along the stream, with an adjacent management zone of an appropriate size to protect the reserve from windthrow.**
5. Stream assessment completed and recipient karst feature identified, but not assessed for significance.	Assume recipient karst feature is **significant**. Establish a minimum 20-metre reserve along the stream, with an adjacent management zone of an appropriate size to protect the reserve from windthrow.**

* See Important Note, page 30.

** Where there are fisheries or community watershed values associated with sinking or losing streams, consult default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act*.

Table 3. Recommended best management practices for:
Streams >3.0 metres in width flowing on karst or non-karst

Results of Stream and Recipient Karst Feature Assessments	Recommended Best Management Practices within the Cutblock*
1. Sinking or losing stream contributes water to a **significant** recipient karst feature located any distance downstream of the cutblock boundary.	Establish a minimum 20-metre reserve along the stream, with an adjacent management zone of an appropriate size to protect the reserve from windthrow.**
2. Sinking or losing stream contributes water to a **non-significant** recipient karst feature located any distance downstream of the cutblock boundary. **OR** Stream does not sink or lose water along its length.	Consult default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act*.
3. No stream assessment carried out.	Assume the stream contributes water to a **significant** recipient karst feature located any distance downstream of the cutblock boundary. Establish a minimum 20-metre reserve along the stream, with an adjacent management zone of an appropriate size to protect the reserve from windthrow.**
4. Stream assessment completed and recipient karst feature identified, but not assessed for significance.	Assume recipient karst feature is **significant**. Establish a minimum 20-metre reserve along the stream, with an adjacent management zone of an appropriate size to protect the reserve from windthrow.**

* See Important Note, page 30.

** Where there are fisheries or community watershed values associated with sinking or losing streams, consult default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act*.

Sinking Watercourses

To qualify as a sinking watercourse, a watercourse must sink into the subsurface at a distinct sink point, and possess one or more of the following characteristics:

- poorly or non-defined channels (including flow over an organic bed);
- exhibit no evidence of scouring or alluvial deposition; or
- flow on the surface for less than 100 metres.

As a minimum threshold, a sinking watercourse must follow a confined, linear drainage course with a distinguishable cross-sectional low point, accompanied by the presence of hydrophytic vegetation (plants that thrive in saturated soils).

Management Objectives

- Sinking watercourses are considered to be less of a management concern than sinking streams because of their lower potential for impacting significant recipient karst features (i.e., sinking watercourses would typically exhibit low-energy water flows, lower transport potential, intermittent or ephemeral flows, etc.). Nevertheless, sinking watercourses have the potential to transport sediment, fine organic material, and small woody debris into the subsurface. For this reason, the management objectives for sinking watercourses are the same as those for sinking streams (see page 31).

Best Management Practices

Where a significant recipient karst feature receives water from a sinking watercourse, the watercourse should be managed in a manner consistent with the management objectives for sinking and losing streams. The following best management practices are recommended within an appropriately sized riparian management zone:

- Retain windfirm trees with roots embedded in the watercourse edge.
- Fall and yard away from the watercourse to the fullest extent possible.
- Avoid yarding across the watercourse.
- Remove slash and debris that inadvertently enter the watercourse.
- Retain windfirm non-merchantable trees and other windfirm vegetation (e.g., understorey, shrubs, herbs) within 5 metres of the watercourse edge.
- Retain windfirm wildlife trees.

These recommended practices, or others deemed appropriate to achieve the management objectives, should be applied for a minimum of 100 metres upstream of the recipient feature or to the point where the watercourse is no longer readily identifiable, whichever is shorter. [**Note:** It is anticipated that in many cases, the reserve and management zone around a significant recipient karst feature will encompass much of the riparian management along sinking watercourses].

VIII. Harvesting Operations

Karst areas classified as very high vulnerability contain sensitive, high resource values. In most cases, it is recommended that very high vulnerability areas be excluded from harvesting operations. Limited exceptions to this may occur in special situations where some form of site-specific intervention is required to help protect forest or karst resources (e.g., forest health issues such as insect infestations). Any forest management activities that may be required on very high vulnerability karst areas should be conducted in consultation with a karst specialist, the Forest Service, and/or other relevant resource agencies.

Best management practices are provided for harvesting operations on low, moderate, and high vulnerability karst areas. These recommended practices are linked to the assessed vulnerability of the karst. As the level of karst vulnerability increases, so do the protective measures of the best management practices.

Figure 9 illustrates the incremental structure of the karst management recommendations.

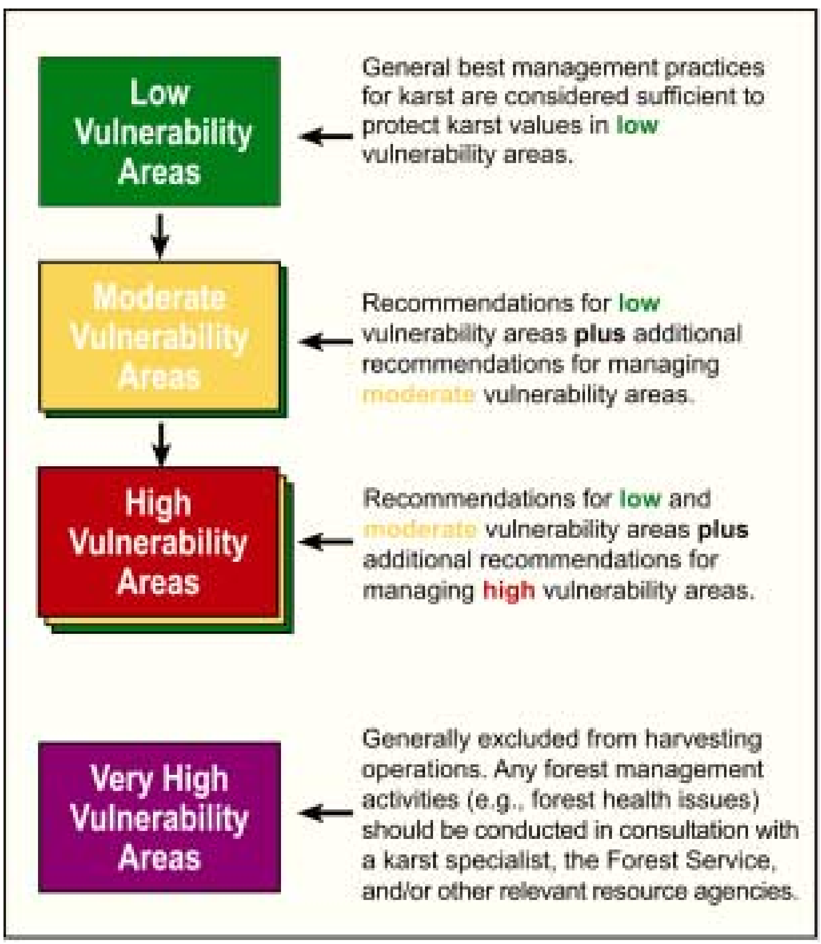

Figure 9. Incremental structure of the karst best management practices.

Road Building and Associated Activities

Karst management issues associated with road building:

- physical damage to surface and subsurface karst features;
- risk of soil erosion and sediment/debris transfer into underground drainage systems and subterranean karst habitats;
- maintenance of natural surface and subsurface drainage patterns;
- maintenance of surface and subsurface water quality and quantity;
- potential for stressing or collapsing caves with thin ceilings (see Figure 10 for definition of caves with thin ceilings);
- inadvertently intercepting subsurface conduits or caves through road and quarry development;
- damage to surface karst features and cave decorations through blasting and/or vibrations from falling timber and hauling heavy loads;
- disturbance to cave-dwelling fauna (e.g., bats) through blasting, construction, or hauling; and
- public access to surface karst features and caves.

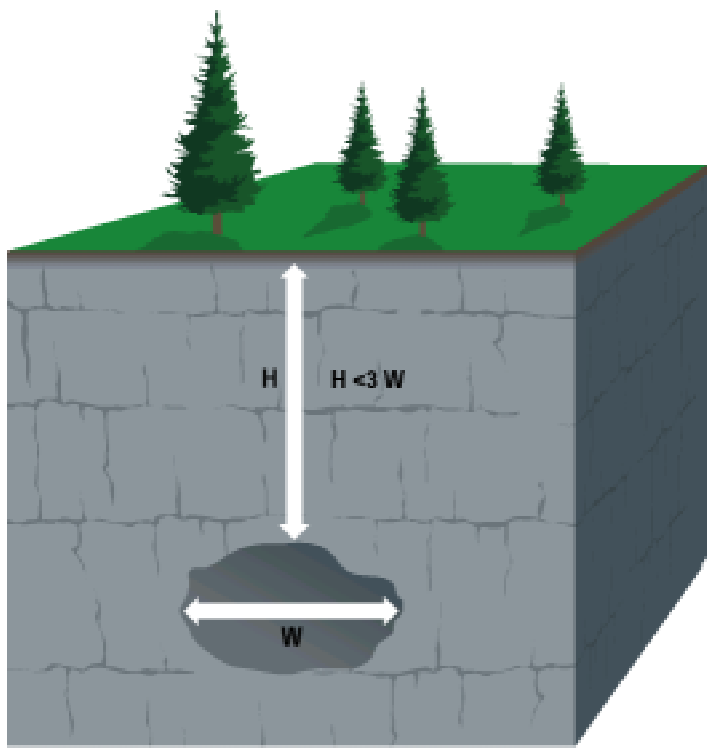

Figure 10. Caves with thin ceilings are defined as “caves where the depth of the overlying bedrock is less than three times the width of the cave passage” (Derek Ford, pers. comm., December 1999)

Engineering challenges associated with road building:

- ground surface instability;
- highly irregular bedrock topography beneath the overburden, leading to unpredictable foundation depths;
- road subsidence, collapse, or washout due to sinkhole development (occasionally induced by changes in drainage caused by roads);
- deep openings or shafts in the bedrock; and
- near-surface cavities and caves with thin ceilings (see Figure 10).

Locating Roads, Landings, and Quarries

A major area of potential conflict with road locations is the fact that logging roads are often located along ridges and areas of higher elevation to achieve easier access to timber and maximum deflection for harvesting (particularly on the coast). These same locations are also where the greatest density of exposed epikarst is typically found. Ideally, roads should not be located on exposed, well-developed epikarst. However, in many cases, there may not be a viable alternative for locating the road. These two issues – the need to protect exposed epikarst and the need for efficient access to timber – will require an innovative management approach (see Road, Landing, and Quarry Construction, Maintenance, Deactivation, and Rehabilitation).

Low and Moderate Vulnerability Areas

The following best management practices are recommended:

- Plan to utilize existing roads, landings, and quarries in preference to building new ones, provided they are environmentally sound.
- Locate quarries on a site-specific basis, accounting for the nature of karst resources in the area and downslope of the area. Avoid depressions (e.g., sinkholes) and other surface karst features. Knolls can be good locations for quarries.
- Whenever possible, locate roads and landings to minimize deep cuts and fills.
- When locating roads, landings, and quarries, attempt to maintain natural surface drainage patterns as much as possible in order to avoid disrupting natural subsurface flows.
- Avoid locating roads, landings, spoil sites, and/or equipment turnaround/turnout sites near surface karst features, cave entrances, or exposed epikarst.
- Avoid locating roads, landings, and quarries within 100 metres of caves known to have fragile formations (decorations) and caves known or suspected to be used by bats or other wildlife sensitive to disturbance (e.g., birds, mammals, rare invertebrates). If circumstances require roads, landings, or quarries to be located closer than 100 metres from such caves, controlled blasting techniques should be designed by a qualified professional to help minimize blast vibrations and sound waves. Where possible, consider scheduling drilling or blasting to accommodate the requirements of wildlife known to be sensitive to disturbance (e.g., avoiding periods when bats are known to be hibernating or when birds may be using the caves for nesting).

In the case of a known bat hibernaculum for a red- or blue-listed species, refer to *Managing Identified Wildlife: Procedures and Measures* (Prov. B.C. 1999) for additional guidance.[7]

- When locating new roads or maintaining existing ones, be aware of the need to avoid facilitating public access to sensitive or hazardous karst areas. Where appropriate measures for managing karst resources feature are in place, consider the need to provide public access to designated karst recreation areas.
- Storage areas for fuel and other hazardous materials should be located off karst terrain or at a minimum on low vulnerability karst areas (except for daily fuel requirements [e.g., gas canisters and tidy tanks]).

High Vulnerability Areas

In addition to the recommendations for low and moderate vulnerability areas, the following best management practices are recommended on high vulnerability areas:

- Limit the planning of new roads and landings to only those locations required for local timber access, or for crossing short sections of high vulnerability karst to access timber on lower vulnerability karst or other terrain.
- Whenever possible, avoid locating mainline or long-term roads and landings on exposed, well-developed epikarst. Attempt to limit roads on these areas to temporary roads that can be readily rehabilitated when no longer needed.
- Avoid locating turnouts and turnarounds on well-developed epikarst.
- Plan to use overlanding road construction techniques as much as possible.
- Roads and landings should not be located over top of caves with thin ceilings (see Figure 10 for illustration and definition). The outline of cave passages known to have thin ceilings should be projected to the surface and clearly marked on the ground. (It may also be prudent to add an appropriately sized 'buffer area' to the cave passage outline as a safety measure.) Caves that cannot be inspected, but are suspected to have thin ceilings, should be assessed by a professional engineer with experience in rock mechanics to evaluate the potential for roof collapse.
- Avoid sinking streams, intermittent or ephemeral surface channels, and dry valleys when locating new roads, as normally minor or dry drainage channels in well-developed karst terrain can be susceptible to periodic back flooding when the capacity of underlying conduits is exceeded during periods of high runoff. Incorporate adequate designs for bridging or culverting these areas if they must be crossed.
- To minimize bridge deck runoff, avoid locating bridge crossings at topographical low points where runoff from road surfaces could accumulate.
- Where possible, avoid quarrying on high vulnerability karst areas due to the potential for well-developed epikarst, the presence or suspected presence of subsurface drainage systems, and the increased occurrence of surface karst features and caves that can be associated with this type of terrain. Wherever practical, locate quarries on nearby or adjacent lower vulnerability karst areas.

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[7] The Managing Identified Wildlife: Procedures and Measures web site is located at: http://wlapwww.gov.bc.ca/wld/identified/species_table_of_contents.htm

- When locating quarries on high vulnerability karst areas is unavoidable, seek the advice of a qualified professional with experience in karst terrain for appropriate site selection.

Road, Landing, and Quarry Construction, Maintenance, Deactivation, and Rehabilitation

A major challenge associated with road construction on karst landscapes is the development of modified/innovative practices to minimize the impacts of road building on exposed epikarst when no other viable road locations exist.

Construction

Low Vulnerability Areas

The following best management practices are recommended:

- Road construction personnel and their supervisors should be thoroughly briefed on the special protective measures recommended for karst landscapes and the safety concerns associated with operating on karst prior to beginning operations (see Appendix III, Safety Recommendations for Forest Management on Karst Terrain). If necessary, on-site discussions between engineering staff and logging personnel/contractors should be conducted.
- Karst features and/or values within the operating area should be flagged or otherwise identified for field crews.
- If a landslide or other disturbance occurs which enters or could enter a significant surface karst feature, cave entrance, or sinking stream, cease operations and notify the local Forest Service district office.
- If previously unidentified karst features or values (e.g., cave entrance, sinkhole, sinking stream, unique or unusual karst flora/fauna) are encountered during road, landing, or quarry construction, activities should be modified or ceased until the features or values are properly assessed, and measures are in place to protect or manage the feature or value. Mark the locations of the features/values in the field and on a map, and notify the local Forest Service district office.
- Avoid construction/maintenance activities during storm events or periods of sustained heavy rainfall to reduce the potential for soil erosion and sediment transfer to the subsurface.
- Avoid importing ballast from non-karst terrain where possible. Non-carbonate rock can be acid-generating, particularly those that contain sulphide minerals such as metallic ores or coal strata. Acid-generating rock can negatively impact the chemistry of karst groundwater.
- After completion of subgrade construction or modification, borrow pits, quarries, endhaul disposal sites, cut and fill slopes, and other disturbed areas should be left in a stable condition to reduce the potential for erosion (avoid backfilling with stumps, logging debris, or other organic debris). Where necessary, apply seed to re-vegetate (hand applications with native species are preferable—avoid hydro-seeding with chemical binding agents).

- Construct temporary access structures, such as skid trails and backspar trails, in a manner that avoids surface karst features, maintains surface drainage patterns, and minimizes surface runoff and soil erosion.

Moderate Vulnerability Areas

In addition to the recommendations for low vulnerability areas, the following best management practices are recommended on moderate vulnerability areas:

- Directionally fall right-of-way trees away from roadside karst features, and use yarding methods (e.g., vertical lift with maximum suspension) that prevent disturbance to nearby karst features (e.g., destabilization of sinkhole sideslopes). Avoid decking right-of-way logs over karst features. Retain residual vegetation around roadside karst features as much as possible.
- Pile any surplus surface material from road, landing, or quarry construction in a safe location (e.g., a protective layer of mineral soil), away from surface karst features and exposed epikarst. Where necessary, haul debris to alternative locations. Ensure that runoff from surplus piles does not enter any surface karst features or streams leading into any surface or subsurface features.
- Avoid drilling or blasting near karst features. If blasting is unavoidable, use minimum or delayed charges, blasting mats, and other mitigating techniques to prevent rock fragments from damaging or landing in surface karst features or cave entrances, or blocking streams flowing into surface karst features or cave entrances.
- Use overlanding road construction methods near roadside karst features.
- Avoid fuelling or servicing machinery near surface karst features and cave entrances. In the event of a fuel spill, remove contaminated forest litter and soil, clean contaminated bedrock surfaces with approved sorbents, and notify the appropriate agencies.
- Keep the wheels or tracks of ground-based equipment at least five metres from the edge of roadside karst features, particularly sinkholes with unstable rims and sideslopes. If not possible, keep the wheels or tracks parallel to the rim, and avoid indenting or otherwise damaging the rim in a way that might lead to destabilizing the sideslopes and/or directing surface drainage water into the feature.
- Avoid removing gravel or fill from roadside depression features.
- Minimize clearing of roadside vegetation as much as possible to provide suitable areas for infiltration of surface runoff.
- To prevent fill slope erosion and contamination of roadside karst features or watercourses, direct the surface runoff from roads and landings to infiltration areas with sufficient vegetation and soil cover. Where necessary, construct settling basins and/or silt/sediment traps to intercept surface runoff with suspended fines before it reaches areas of exposed epikarst, surface karst features, cave entrances, or sinking streams. Attempt to design and install settling basins and/or silt/sediment traps that function with minimal maintenance.
- Complete road and landing construction with sufficient time to allow for the adequate re-vegetation (e.g., grass seeding) of cut and fill slopes so they do not sit bare and vulnerable to erosion throughout the wetter months of the

year. (Hand applications with native species are preferable—avoid hydro-seeding with chemical binding agents.)

- Consider leaving roads across sections of exposed carbonate bedrock unsealed to reduce runoff. Where sedimentation of groundwater is a potential hazard, use geotextile materials to prevent the migration of fines.
- Where practical, crown the surface of sealed roads to facilitate lateral diffuse drainage.
- Direct runoff from bridge decks away from stream channels and into vegetated cover along the stream banks. To minimize potential sedimentation problems, use geotextile materials on the bridge deck and around bridge ends (cribs and sills).
- To help prevent contamination of karst waters, avoid the use of chemically treated wood for bridges.

High Vulnerability Areas

In addition to the recommendations for low and moderate vulnerability areas, the following best management practices are recommended on high vulnerability areas:

- When building roads on exposed epikarst, avoid damage to the epikarst and prevent sediment transport into underground aquifers as much as possible. Exposed, well-developed epikarst should only be crossed by relatively short segments of temporary road that can be readily rehabilitated. Consider using the following specialized road construction techniques:
  - Use overlanding road construction methods as much as possible. Avoid or minimize grubbing. Attempt to flush-cut stumps and avoid pulling stumps.
  - Minimize clearing widths, road widths, and landing surface areas as much as possible to reduce runoff and potential erosion problems.
  - Use the largest possible ballast material with a suitable range in grade to build up the road, to span or infill epikarst cavities, and to minimize runoff from the road surface. Avoid the use of fine materials when road building on these areas. (Roadside ditches are generally not necessary since water tends to percolate directly into the karstified bedrock before it has time to collect in surface streams.)
  - To avoid damaging high vulnerability epikarst, obtain ballast material from nearby low or moderate vulnerability areas whenever possible.
  - Use geotextile materials to help minimize sediment transfer into the subsurface. Consider the use of geogrids for spanning epikarst cavities.
  - Consider using bridging mechanisms (e.g., untreated log stringer bridges) to raise or span the road over short sections of highly significant/sensitive epikarst features.
- Where practical, substitute rock drilling/hammering for blasting on well-developed epikarst. Where blasting is used, seek the advice of a qualified professional for assistance in developing techniques to minimize impacts to the epikarst as much as possible.
- When blasting in the vicinity of surface karst features or caves that may be used for recreation, close the area to the public and post warning signs until

operations cease. Be aware of the potential impacts on air quality in caves and underground passages through the transport of noxious gases, vapours, and suspended particles. These toxic substances can be carried great distances by subsurface air flows to potentially impact cave visitors and subterranean biota.

Maintenance

Best Management Practices for All Vulnerability Categories

The following best management practices are recommended:

- Maintain silt/sediment traps and drains to function properly. Dispose of or store any accumulated debris away from karst features and watercourses leading to karst features.
- Minimize accumulations of graded materials along roadsides where sediment could enter surface features or streams leading into surface or subsurface features.
- Avoid the use of chemical dust suppressants, de-icing agents, and salt on roads.
- Storage areas for fuel and other hazardous materials should be located off karst terrain or, at a minimum, on low vulnerability karst areas (except for daily fuel requirements [e.g., gas canisters and tidy tanks]).
- Avoid fueling or servicing machinery near surface karst features and cave entrances. In the event of a fuel spill, remove contaminated forest litter and soil, clean contaminated bedrock surfaces with approved sorbents, and notify the appropriate agencies.

Deactivation and Rehabilitation

Best Management Practices for All Vulnerability Categories

The following best management practices are recommended:

- Consider deactivating roads and landings after completion of operations to restrict public access to sensitive or hazardous karst areas. Roads that provide access to designated karst recreation areas should be kept open (consult with the local Forest Service district office to discuss access management).
- When carrying out temporary deactivation, remove or frequently breach windrows on the outer edge of road surfaces.
- If there is a risk of erosion adversely affecting the road or roadside karst features when temporarily deactivating a road, construct water bars or cross-ditches, or inslope or outslope the road as required.
- When permanently deactivating a road where sedimentation could be a problem, consider armouring drainage ditches (cross-ditches and roadside) for long-term erosion control.
- Quarries should not be used as storage sites (temporary or otherwise) for logging debris/wood waste, refuse, petroleum products, etc. When deactivating a quarry, take measures to make it inaccessible to dumping from the general public (e.g., berms, waterbars).
- Upon completion of operations, adequately deactivate quarries where sediment or drainage water from the quarry could potentially enter surface

karst features or streams flowing into surface or subsurface features. Deactivation may include directing runoff onto infiltration sites with adequate vegetation and soil cover, redistributing overburden, and re-vegetation (hand applications with native species are preferable—avoid hydro-seeding with chemical binding agents). In situations where redistributing the overburden could result in sediment transfer to karst groundwater, avoid redistribution or alternatively use suitable materials (e.g., geotextiles) to prevent the transport of fines.

- When rehabilitating roads and landings, or temporary access structures, restore natural surface drainage patterns as much as possible to maintain the quantity and quality of subsurface flows.
- Avoid rehabilitating roads and landings, or temporary entry trails, during storm events or periods of sustained heavy rainfall.
- Avoid road deactivation or rehabilitation in cases where disturbance to the roadbed may be detrimental to karst values in the area (e.g., sediment transfer to the subsurface).
- When rehabilitating or deactivating roads and landings, keep the wheels or tracks of ground-based equipment at least five metres from the edge of roadside karst features, particularly sinkholes with unstable rims and sideslopes. Where this is not possible, keep the wheels or tracks parallel to the rim, and avoid indenting or otherwise damaging the rim in a way that might lead to destabilizing the sideslopes and/or directing surface drainage water into the feature.
- Avoid introducing soil or road and landing bedding materials into roadside karst features during deactivation or rehabilitation activities.
- Attempt to complete rehabilitation operations with sufficient time to allow for adequate re-vegetation so the area does not sit bare and vulnerable to erosion throughout the wetter months of the year. (Hand applications with native species are preferable—avoid hydro-seeding with chemical binding agents.)

Timber Harvesting

Karst management issues associated with timber harvesting:

- minimizing the disturbance of sensitive karst soils to prevent soil erosion/loss and sediment transfer into subsurface karst environments. [**Note:** The potential for rapid vertical transfer of large quantities of soil into epikarst cavities or subsurface conduits is a management concern unique to three-dimensional karst landscapes. Significant soil erosion can occur on even gentle slopes or flat terrain with well-developed epikarst, where no erosion problems would be anticipated on a non-karst landscape of similar slope].
- maintenance of surface and subsurface water quality and quantity;
- maintenance of stable microclimates around significant cave entrances;
- maintenance of critical karst processes on the surface above significant caves (e.g., vegetative cover, soil flora and fauna, drip water chemistry);
- protection of significant surface and subsurface karst features;
- protection and conservation of karst-dependent flora and fauna (e.g., bats); and
- maintenance of the recreational setting and experience for significant surface karst features and cave entrances.

Low Vulnerability Areas

The following best management practices are recommended:

- Harvesting personnel and their supervisors should be thoroughly briefed on the special protective measures recommended for karst landscapes and the safety concerns associated with operating on karst prior to beginning operations (see Appendix III, Safety Recommendations for Forest Management on Karst Terrain). If necessary, on-site discussions between engineering staff and logging personnel/contractors should be conducted.
- Karst features and/or values within the operating area should be flagged or otherwise identified for field crews.
- If previously unidentified karst features or values (e.g., cave entrance, sinkhole, sinking stream, unique or unusual karst flora/fauna) are encountered during harvesting, activities should be modified or ceased until the features or values are properly assessed, and measures are in place to protect or manage the feature or value. Mark the locations of the features/values in the field and on a map, and notify the local Forest Service district office.
- Minimize exposing mineral soil as much as possible during logging operations.
- Storage areas for fuel and other hazardous materials should be located off karst terrain or, at a minimum, on low vulnerability karst areas (except for daily fuel requirements [e.g., gas canisters and tidy tanks]).

Moderate Vulnerability Areas

In addition to the recommendations for low vulnerability areas, the following best management practices are recommended on moderate vulnerability areas:

- In areas where erosion and sediment transfer to karst groundwater are likely to occur, consider restricting harvesting to periods when the probability of heavy rains and high runoff are low.
- Consider developing site-specific procedures for closely spaced, dense occurrences of minor surface karst features.[8] For example, impacts on these areas can be minimized by falling and yarding away from features, retaining non-merchantable vegetation around features, removing any logging debris from features, avoiding the construction of skid trails over obvious minor features, etc. In some cases, it may be more practical to treat a cluster of minor features as a single large feature or unit (see Figure 11).

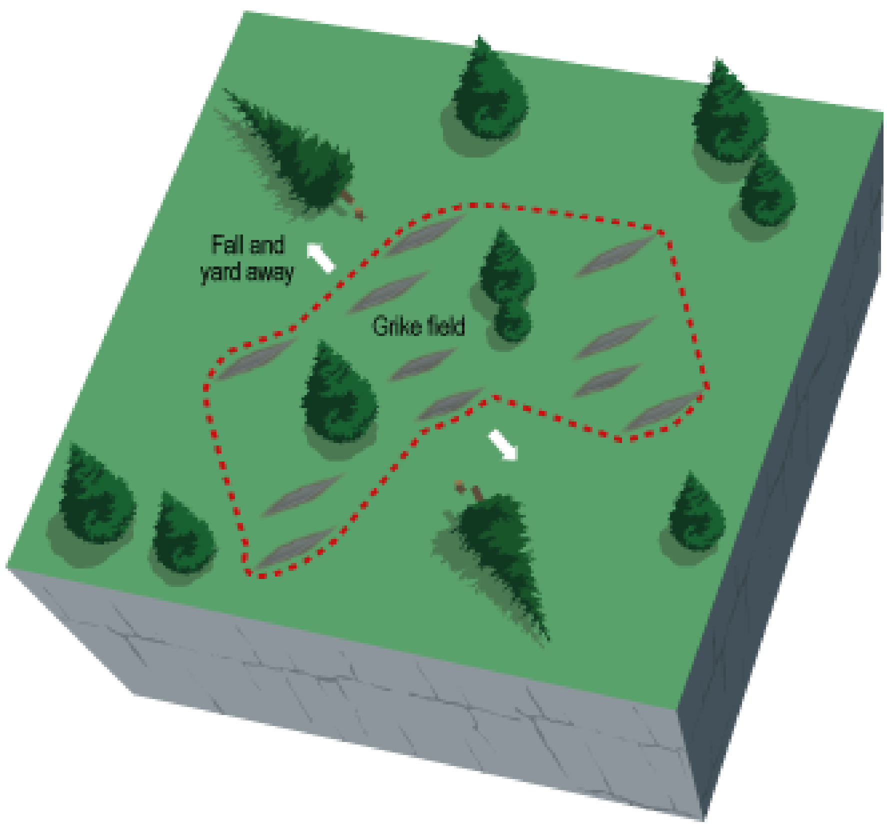

Figure 11. Example of treating a cluster of minor surface karst features as a single unit.

- When harvesting sinkholes not classified as significant (i.e., no reserve recommended), avoid disturbance to sideslopes and minimize soil disturbance as much as possible (e.g., fall and yard away, retain non-

[8] Minor surface karst features – surface karst features of relatively small size, rarely more than five metres in the greatest dimension (e.g., karren, small sinkholes, grikes, residual pinnacles, or other surface solutional features).

merchantable vegetation, maximum suspension yarding). Harvesting these types of sinkholes with >70% sideslopes should be carried out very carefully due to the high potential for soil erosion.

- Where falling away from a sinkhole cannot be reasonably achieved, and remaining trees threaten sideslope stability due to windthrow potential, consider falling across the sinkhole if the tree stem will span the feature and can be lifted without damaging the sideslope. If removal will damage residual trees or sideslopes, leave the section of stem spanning the feature, provided it is stable.
- To recover introduced logging slash and debris from a sinkhole, consider the following:
  - Clean out introduced debris only if it can be done without causing further disturbance.
  - Avoid using heavy machinery where damage to sideslopes could occur.
  - Where necessary, follow machine cleaning with hand cleaning to remove fine debris.
  - Leave naturally fallen trees intact.
  - Do not remove stable natural material embedded in sinkhole sideslopes or root systems that contribute to sideslope stability.
- Keep the wheels or tracks of ground-based equipment at least five metres from the edge of karst features, particularly sinkholes with unstable rims and sideslopes. If not possible, keep the wheels or tracks parallel to the rim, and avoid indenting or otherwise damaging the rim in a way that might lead to destabilizing the sideslopes and/or directing surface drainage water into the feature.
- Inadvertent water diversions that occur during logging operations (from slash accumulation, etc.) should be dispersed and rectified as soon as possible to prevent potential sediment transport into subsurface environments.
- Where necessary, use a protective mat to minimize soil disturbance when hoe chucking.
- Keep skid trails and backspar trails to a minimum and located away from surface karst features and cave entrances. Attempt to keep to designated trails.
- Attempt to achieve maximum suspension yarding whenever practical to minimize the potential for soil disturbance/erosion.
- Avoid fueling or servicing machinery near surface karst features and cave entrances. In the event of a fuel spill, remove contaminated forest litter and soil, clean contaminated bedrock surfaces with approved sorbents, and notify the appropriate agencies.

High Vulnerability Areas

In addition to the recommendations for low and moderate vulnerability areas, the following best management practices are recommended on high vulnerability areas:

- Be aware that harvesting on well-developed epikarst with shallow and/or finely textured, erodible soils could potentially result in significant soil erosion and loss of soil into deep epikarst cavities or subsurface conduits, leading to lower site productivity and the sedimentation of underground drainage systems and caves. To minimize soil disturbance and maintain site productivity on these sites, consider using partial-cutting systems and/or attempt to achieve maximum or total suspension. Rubber mats should be used when hoe chucking. On areas where even minimal soil disturbance would result in significant soil loss, helicopter logging may be a viable option.

- To prevent exposing forest workers to the dangers of sudden roof collapse when harvesting over caves known or suspected to have thin ceilings (see Figure 10):
  - Project the outline of the cave passages (if known) to the surface, and clearly mark on the ground. (It may also be prudent to add an appropriately sized 'buffer area' to the cave passage outline as a safety measure.)
  - Avoid the use of heavy machinery.
  - Assess the size and weight of the timber being felled.
  - Fall and yard away from the underlying cave as much as possible.
  - Avoid decking logs on the surface above the cave.
- Avoid piling slash on exposed, well-developed epikarst; use road prisms where possible, except where such piling could result in destabilizing road prisms (e.g., on steep slopes).
- Where trees have fallen in or near significant cave entrances or significant surface karst features (e.g., due to windthrow), attempt to remove the timber if it can be done without causing more disturbance. Use full suspension yarding, if possible.

Post-harvest Operations

Karst management issues associated with post-harvest operations:

- impacts of burning, particularly on karst with shallow, organic soils;
- impacts of herbicides and fertilizers on karst groundwater;
- soil disturbance associated with mechanical methods of site preparation; and
- the potential for obstructing or clogging surface karst features and cave entrances with spacing and pruning debris.

Herbicides

Low Vulnerability Areas

The following best management practices are recommended:

- Before deciding to use herbicides, evaluate the sensitivity of the karst resources in the area and the potential for detrimental impacts on karst systems and processes.
- Careful consideration should be given to selecting an appropriate herbicide for the type of karst terrain being treated (e.g., toxicity levels, chemical pathways, breakdown rates).
- Aerial applications of herbicides should be limited to karst areas with sufficiently thick soil and/or till cover to breakdown the herbicide before it can leach into groundwater and subsurface environments.

Moderate Vulnerability Areas

In addition to the recommendations for low vulnerability areas, the following best management practice is recommended on moderate vulnerability areas:

- Keep herbicide applications well away from sinking and losing streams, surface karst features, cave entrances, and exposed epikarst.

High Vulnerability Areas

In addition to the recommendations for low and moderate vulnerability areas, the following best management practice is recommended on high vulnerability areas:

- Herbicides should not be used on high vulnerability areas where the characteristically thin soils and open nature of the karst would lead to the rapid transfer of herbicides to karst groundwater and subsurface environments. If herbicides must be used, employ ground spot treatments (e.g., hack and squirt).

Mechanical Operations – Site Preparation and Vegetation Management

Low and Moderate Vulnerability Areas

The following best management practices are recommended:

- During mechanical site preparation or vegetation management operations, attempt to keep the wheels or tracks of ground-based equipment at least five metres from the edge of karst features, particularly sinkholes with unstable rims and sideslopes. Where this is not possible, keep the wheels or tracks parallel to the rim, and avoid indenting or otherwise damaging the rim in a way that might lead to destabilizing the sideslopes and/or directing surface drainage water into the feature.

- Avoid mechanical methods of site preparation and vegetation management on areas where mineral soils overlying epikarst are thin.
- Avoid pulling stumps during site preparation where the practice could result in significant soil erosion and/or the transfer of soil into epikarst cavities.

High Vulnerability Areas

In addition to the recommendations for low and moderate vulnerability areas, the following best management practice is recommended on high vulnerability areas:

- Mechanical forms of site preparation or vegetation management are inappropriate on high vulnerability karst areas. The level of disturbance would be too high for the characteristically thin organic soils and highly permeable epikarst.

Burning

Low Vulnerability Areas

The following best management practice is recommended:

- Consider the potential impacts of burning on nearby or adjacent higher vulnerability karst areas (e.g., smoke entering significant caves can reduce air quality for cave fauna and recreationists, and affect delicate cave formations).

Moderate Vulnerability Areas

In addition to the recommendation for low vulnerability areas, the following best management practices are recommended on moderate vulnerability areas:

- Limit burning to spot or small pile burning, or light spring broadcast burns, in areas where the soil cover is sufficiently thick to protect underlying karst resources.
- Use road prisms and/or landings for burning sites wherever practical.
- Avoid piling and burning slash on exposed epikarst, or near surface karst features or cave entrances.
- Avoid the use of chemical fire retardants/suppressants.
- As an alternative to burning, consider accumulating and leaving slash in small piles; locate these piles away from exposed epikarst, surface karst features, and cave entrances.

High Vulnerability Areas

In addition to the recommendations for low and moderate vulnerability areas, the following best management practice is recommended on high vulnerability areas:

- Broadcast burning should not occur on high vulnerability areas.

Reforestation

Best Management Practices for All Vulnerability Categories

The following best management practices are recommended:

- Ensure prompt reforestation after harvesting and consider using larger stock types to help minimize brush problems and reduce the need for vegetation management.
- When planting, avoid major changes in tree species to maintain consistency in the forest type and litter biota, which can influence karst processes (surface and subsurface).
- Alternative stocking standards may be appropriate (e.g., cluster planting, reduced minimum inter-tree distance) on some areas due to limited growing sites associated with exposed bedrock and outcrops.

Stand Tending

Best Management Practices for All Vulnerability Categories

The following best management practices are recommended:

- Stand tending crews should be made aware of the protective measures associated with karst features and attributes. If a karst field assessment is available for the area, the crew should be fully advised of the results and given clear direction for carrying out stand tending operations. If a karst field assessment has not been done, one should be completed to identify specific karst features requiring special management, to assess the vulnerability of the broad karst landscape, and to provide guidance for appropriate stand tending measures.
- Keep spacing and pruning debris clear of surface karst features, cave entrances, watercourses flowing into features, and established trails leading to surface karst features or caves.

Fertilizing

Best Management Practices for All Vulnerability Categories

The following best management practice is recommended:

- Avoid using aerial broadcast applications of fertilizers that could contaminate karst groundwater and subterranean environments/habitats. Consider using spot applications as an alternative.

Rehabilitation of Degraded Features and Sites

Best Management Practices for All Vulnerability Categories

The following best management practices are recommended:

- When considering rehabilitating degraded features or sites, each case should be evaluated individually to determine if rehabilitation efforts would be successful or lead to more disturbance. Where more damage could occur as the result of rehabilitation, avoid undertaking any action or discontinue operations.

- Rehabilitation efforts may include:
  - stabilizing sinkhole sideslopes with grass seeding (hand applications with native species are preferable; avoid hydro-seeding with chemical binding agents);
  - modifying tree planting where soil has been lost into epikarst cavities (e.g., concentrate planting in soil-filled solutional openings); or
  - removing logging debris or windthrow from sinking streams, surface karst features, and cave entrances.
- Where possible, use low ground-pressure equipment and rubber mats for recovering debris in or near sinkholes with unstable rims and sideslopes. Keep the wheels or tracks of the equipment at least five metres from the edge of sinkholes. If not possible, keep the wheels or tracks parallel to the rim, and avoid indenting or otherwise damaging the rim in a way that might lead to destabilizing the sideslopes and/or directing surface drainage water into the feature. Where necessary, use hand cleaning and/or full suspension methods (e.g., helicopter) to remove debris.

IX. Management Strategies for the Non-karst Portions of Karst Catchment Areas

Karst catchment areas are comprised of all lands contributing surface runoff and/or diffuse recharge to a karst system, including upstream non-karst areas. The non-karst portions of a catchment area should be managed effectively to protect the resource values of downstream karst units. [**Note:** Karst catchments are delineated during karst inventories (see RISC 2003). The use of dye tracing may be appropriate to determine subsurface flow paths, particularly in cases where subsurface hydrological connections cross surface drainage divides].

The primary management objective for the non-karst portion of a karst catchment area is to maintain the water quality and quantity of streams that sink or lose water into downstream karst units. Where downstream karst resources are significant and vulnerable to inputs of sediment and debris from sinking or losing streams, temperature fluctuations, or changes in flow characteristics, some modification to default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act* may be necessary. Surface streams flowing off the non-karst portion of a karst catchment that do not sink or lose water to a downstream karst unit can be managed following the riparian management default standards as specified in the regulations supporting the *Forest and Range Practices Act*.

Non-karst Catchments Contributing to Low Vulnerability Areas

- Default standards for riparian management as specified in the regulations supporting the *Forest and Range Practices Act* are sufficient to protect karst resources.

Non-karst Catchments Contributing to Moderate and High Vulnerability Areas

- Follow the recommendations for managing sinking and losing streams as outlined in Riparian Management for Sinking and Losing Streams/Sinking Watercourses, page 30.

Non-karst Catchments Contributing to Very High Vulnerability Areas

- Very high vulnerability karst areas will likely contain provincially or even nationally and internationally significant karst resources. Those features with direct hydrological inputs from the non-karst portion of the catchment area will likely be highly sensitive to fluctuations in water quality, water quantity, nutrient content, and water chemistry.
- The potential for increased runoff, higher stream velocities, and increased sediment and debris transport should be considered when developing

management strategies for non-karst catchment areas draining into very high vulnerability areas.

- Consider the use of partial-cutting systems, smaller dispersed cutblocks, maximum suspension yarding, and extended rotation periods to reduce the impacts of increased runoff resulting from harvesting.
- In some cases, a watershed assessment may be necessary to determine an appropriate equivalent clearcut area (ECA) for the non-karst catchment area.
- Sinking and losing streams should be managed as outlined in Riparian Management for Sinking and Losing Streams/Sinking Watercourses, page 30.

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Glossary

Archaeology – the scientific study of the physical evidence of past human cultures.

Armouring – placing non-erodible material (e.g., riprap) over material that may be subject to erosion.

Ballast – rock, gravel, or other stabilizing material placed on top of subgrade or overland ground during road building.

Carbonate bedrock – rock consisting mainly of the carbonate minerals calcite and dolomite.

Catchment – the surface area drained by various sized watercourses.

Cave – a natural cavity in the earth that connects with the surface, contains a zone of total darkness, and is large enough to admit a human. For the purposes of cave management, this term should also include any natural extensions, such as crevices, sinkholes, pits, or any other openings, that contribute to the functioning of the cave system.

Cave decorations – secondary mineral deposits formed in caves; synonym, speleothems.

Caves with thin ceilings – Caves where the depth of the overlying bedrock is less than three times the width of the cave passage. (Derek Ford, pers. comm., December 1999) (See Figure 10.)

Conduit – a subsurface stream course completely filled with water, and always under hydrostatic pressure.

Cross-ditches – ditches excavated across a road at an angle, and at sufficient depth, with armouring as appropriate, to divert both road surface water and ditch water across the road.

Dolomite – a mineral composed of calcium magnesium carbonate. Rock is chiefly composed of the mineral dolomite. Also called dolostone.

Dry valley – a valley that lacks a surface water channel.

Endhaul – to move excavated material from one section of a road to another, or to a disposal site, during road construction or modification.

Ephemeral stream – a stream or portion of a stream that flows only in direct response to precipitation, drying up shortly after precipitation ceases.

Epikarst – the upper surface of karst, consisting of a network of intersecting fissures and cavities that collect and transport surface water and nutrients underground; epikarst depth can range from a few centimetres to tens of metres.

Geotextile material – a synthetic material placed under road fill, bridges, or reinforced slopes with the primary purpose of limiting fine aggregate transfer.

Grubbing – removal of stumps, roots, embedded logs, organics, and unsuitable soils before, or concurrently with, subgrade road construction.

Grike – a deep, narrow, vertical or steeply inclined rectangular slot in carbonate bedrock, developed by solution along a joint or fracture.

Gypsum – the mineral, hydrated calcium sulfate.

Halite – the mineral form of sodium chloride (NaCl), or rock salt.

Karren – channels or furrows separated by ridges resulting from solution on bedrock surfaces; the term is also used broadly to describe a variety of superficial solution forms on the surface of bedrock.

Karst resources – refers to all components of a karst system, including the physical, biological, and aesthetic aspects of a karst landscape.

Karst spring – underground stream that emerges at the surface; also known as a rising stream.

Limestone – a sedimentary rock comprised primarily of calcite.

Marble – limestone that has been recrystallized and hardened by heat and pressure.

Overburden – material of any nature (soil, sand, silt, clay), consolidated or unconsolidated, that overlies deposits such as bedrock, ores, or coal.

Overlanding – placing road construction fill over unstripped organic soil, stumps or other vegetative materials for the purpose of distributing vertical loads over soft ground, whether or not the fill is supported by corduroy or geotextiles.

Paleontology – science that studies fossil remains, both plant and animal, from past geological ages.

Physiographic – pertaining to the origin and evolution of landforms.

Road deactivation – measures taken to stabilize roads and logging trails during periods of inactivity, including the control of drainage/runoff, the removal of sidecast where necessary, and the re-establishment of vegetation where permanent deactivation is required.

Road rehabilitation – involves the removal of a road and restoration of the original slope and natural drainage patterns to prevent erosion and re-establish site productivity.

Settling basin – small ponds or basins where water flows are contained to enable suspended sediment to settle before the flow is discharged into a stream.

Shaft – a deep vertical or nearly vertical solution hole, generally cylindrical in shape, with no passages or chambers leading from it.

Sidecast – moving excavated material to the downslope side during road and landing construction.

Significant surface karst feature – details for determining the significance of surface karst features are provided in Appendix C of *Karst Inventory Standards and Vulnerability Assessment Procedures* (RISC 2003).

Significant cave – information on classifying caves for their significance is provided in RISC (2003).

Silt/Sediment trap – a device for trapping or otherwise preventing silt or sediment from entering a stream (e.g., silt fence, filter fabric).

Sinkhole – a topographically closed karst depression, wider at the rim than it is deep; commonly of a circular or elliptical shape with a flat or funnel-shaped bottom.

Solutional cavities – cavities formed primarily by the solution action of water on carbonate bedrock.

Sorbents – materials capable of adsorption (attracting and holding substances upon its surface [e.g., charcoal]) and absorption (sucking in and holding a substance within a porous material [e.g., sponges]) used to clean up spills.

Speleothems – secondary mineral deposits formed in caves, such as stalactites or stalagmites. Also known as cave formations or cave decorations.

Subgrade construction – removal of obstacles and materials necessary for the construction of a road.

Subsidence – movement in which surface materials are displaced vertically downward, with little or no horizontal component.

Swallet – location where a stream sinks underground, often associated with a stream flowing into a cave entrance; also swallow hole.

Troglobite – a creature that lives permanently underground, beyond the daylight zone of caves, and cannot survive outside the cave environment.

Troglophile – a facultative cave-dwelling animal that may complete its life cycle in a cave, but can also survive in above ground habitats.

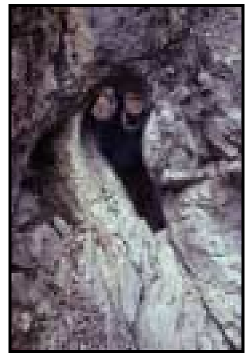
Trogloxene – an animal that enters caves for various reasons, but does not live there permanently (e.g., bats).

Waterbars – shallow ditches excavated across a road at an angle to prevent excess surface flow and subsequent erosion of road surface materials.

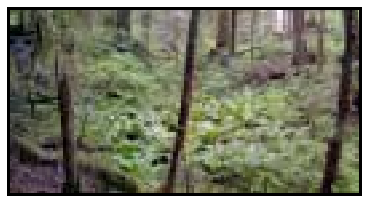
Windthrow – uprooting of trees by the wind.

Appendix I.
Illustrated Glossary of Karst Features

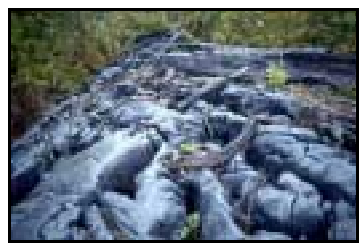
Cave entrance – surface openings large enough to admit a human that connect to interior cavities containing a zone of complete darkness.



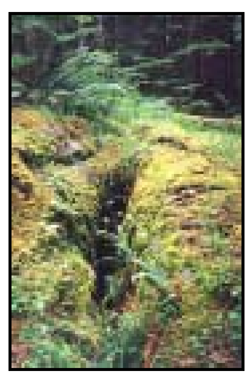
Dry valley – a valley that lacks a surface water channel.



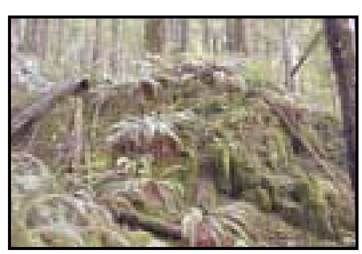
Epikarst – the upper surface of karst, consisting of a network of intersecting fissures and cavities.



Grike – a deep, narrow, vertical or steeply inclined rectangular slot in carbonate bedrock developed by solution along a joint or fracture.



Hum – a small residual hill of soluble rock standing above an eroded soluble rock surface.

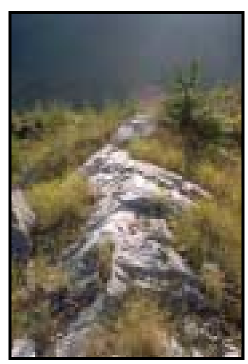


Karren – channels or furrows separated by ridges resulting from solution on bedrock surfaces.

Karst canyon – a deep, narrow gorge or ravine underlain by soluble rock containing a perennial or intermittent stream.

Karst pond – a karst depression enclosing a standing water body.

Karst ridge – a long, narrow hill of soluble bedrock.



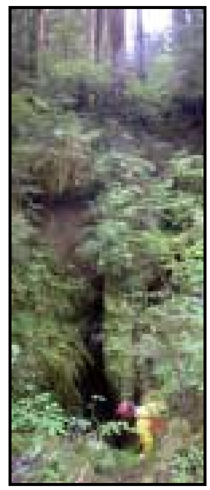
Karst spring – a feature where water is discharged to the surface from subsurface flows.

Natural arch – a small, natural rock bridge that does not span a karst valley.

Natural bridge – a large, natural rock bridge spanning a karst valley.

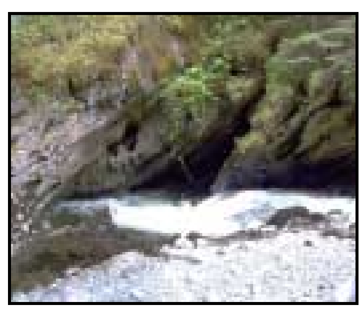
Rock shelter – a solution hollow reaching a short way into a hillside or under a fallen block.

Shaft – a deep vertical or nearly vertical solution hole, generally cylindrical in shape, with no passages or chambers leading from it.



Sinkhole – a topographically closed karst depression, wider at the rim than it is deep; commonly of a circular or elliptical shape, with a flat or funnel-shaped bottom.

Swallet – a feature where surface water or a stream flows into the subsurface.



Appendix II. Descriptions of Karst Vulnerability Classes

The following descriptions are examples of the four possible karst vulnerability ratings derived during a karst field assessment, based on forested karst sites in British Columbia. These examples do not cover all potential scenarios; however, they do provide some indication of the typical terrain and karst conditions that might be expected.

Low Vulnerability

Low vulnerability karst areas could include a range of terrain conditions that vary from moderately steep sloping karst surfaces with thin soil cover, little epikarst development, and no karst features, to a gentle to moderate sloping bench with a thick till blanket, moderately developed epikarst, and isolated surface karst features. An example of low vulnerability terrain in Coastal British Columbia might be a valley bottom with thick surficial material, evidence of epikarst development only exposed in road cuts, and no obvious surface karst features. An example in the Interior might include a valley bottom or low elevation site with thick till cover, no observable epikarst development, and no surface karst features.

Moderate Vulnerability

Moderate vulnerability karst areas could include a relatively wide range of terrain conditions. These conditions could include moderately to well-developed epikarst, with a thin soil veneer, and a low number of surface karst features (e.g., one to five per hectare). Alternatively, terrain conditions could include a blanket of soil, with slight to no epikarst development, and a moderate number of surface karst features (e.g., five to 10 per hectare). In most cases, it would be anticipated that a moderate or possibly high potential for subsurface openings exists. An example of moderate vulnerability terrain in coastal British Columbia might include a lower to mid elevation site with undulating terrain, a blanket of surficial material, some dispersed epikart exposures, and occasional surface karst features such as sinkholes and grikes. An example of moderate vulnerability terrain in the Interior might be a gentle to moderate sloping bench, with a blanket of till cover, little to no epikarst development, and occasional surface karst features such as springs.

High Vulnerability

High vulnerability karst areas could include terrain with moderate to well-developed epikarst, a high density of surface karst features (e.g., 10 to 20 per hectare), and a high likelihood for subsurface openings and caves. An example of high vulnerability terrain in coastal British Columbia might include a gentle sloping bench, with a thin till veneer exposing a distinct solutional epikarst that is interspersed with a number of surface karst features, including cave entrances. A series of sinking streams and swallets could also be present at the upper geological contact of the bench, further confirming the presence of subsurface openings. The likelihood of encountering high vulnerability karst in forested areas in the Interior is expected to be much lower than for the Coast.

Very High Vulnerability

Very high vulnerability karst areas would include terrain with a combination of well-developed epikarst, a very high density of surface karst features (e.g., more than 20 per hectare), and known caves. There would be a high level of connectivity between the surface and subsurface. An example of very high vulnerability terrain in coastal British Columbia might include a moderate sloping bench, with a trace of forest floor cover over a very irregular surface, exposing extensive areas of deep solutional epikarst, interspersed by numerous single and coalescing surface karst features (e.g., sinkholes, grikes, and cave entrances). The cave entrances could lead into significant cave systems with well-developed or fragile decorations, critical habitat for cave fauna, important scientific values, or highly valued recreational opportunities. It is anticipated the likelihood of encountering very high vulnerability karst in forested areas in the Interior would be rare.

Appendix III.
Safety Recommendations for Forest Management on Karst Terrain

Karst landscapes can be hazardous areas for forest workers and the general public. Safety concerns associated with karst terrain include:

- ground hazards, such as deep vertical shafts, grikes, sinkholes, and thin ceiling caves;
- water hazards such as swallets;
- blasting in fractured limestone and exposed epikarst;
- road subsidence or sudden collapse due to sinkhole formation; and
- managing public access to potentially hazardous surface karst features or caves.

Worker Safety

Best Management Practices

The following best management practices are recommended:

Layout and Design

- During the layout and design phase, identify all site hazards on a working field map. All surface karst features (e.g., cave entrances, sinkholes, grikes, swallets) that could potentially pose a safety hazard to forest workers should be clearly flagged or otherwise identified on the ground (signs could also be placed within the cutblock indicating potential hazards).

Worker Training and Extension

- Inform forest workers of the hazards and safety concerns associated with operating on karst terrain.
- Consider holding "tailgate" sessions prior to initiating operations to discuss site-specific safety concerns associated with the work area.
- Forest workers should avoid working alone on karst terrain, or should, at a minimum, carry radios and institute a worker-check system in case of accidents.
- Discourage workers from entering caves or surface karst features discovered on work sites.

Roads

- Blasting in limestone can be more dangerous to workers due to the highly fractured nature of limestone (more flying rock), and the connectivity between the surface and subsurface. Blasts and associated shock waves can travel along subterranean conduits and escape back to the surface through karst openings such as grikes or vertical shafts. Workers should protect themselves from flying rock, and avoid taking cover from blasts near any

- surface karst features with connections to the subsurface. Where appropriate, rubber mats should be used to contain rock at the blast site.
- For appropriate blasting techniques in limestone, crews should receive extra training for recommended drilling patterns, types and volumes of charges, and methods for dealing with unstable overhangs (e.g., bolting or scaling).
- When using roads through karst terrain, especially areas of high vulnerability, be aware that roads can be susceptible to subsidence or sudden collapse due to sinkhole formation. Drivers should pay extra attention to road conditions.

Logging

- Use caution when on the work site. Dangerous surface openings, such as vertical shafts, grikes, and sinkholes, can be hidden by forest litter, root masses, and logging slash. Be aware that trees felled in hummocky karst terrain can be unstable and susceptible to sudden movement when disturbed.

Post-harvest

- Flags and markers around surface karst features should be maintained on site after logging operations cease to identify hazards for workers conducting post-harvest silviculture treatments, such as planting, spacing, or pruning.

Public Safety

Best Management Practices

The following best management practices are recommended:

Signage

- Where public recreation sites and trails are maintained on karst landscapes, posting warning signs at parking areas and hazardous sites may be appropriate. This may involve cooperating with the Forest Service, outdoor recreation agencies, public education programs, or, in the case of caves, with caving organizations and commercial cave operators.

Access Management

- Where possible, restrict public access to maps indicating the locations of hazardous surface karst features and caves.
- For extremely hazardous surface karst features and caves that may place the public at unreasonable risk, consider closing the area and deactivating roads to remove access. Contact the local Forest Service district office for guidance.

Appendix IV.
Range Land Management on Karst Terrain

Karst management issues associated with range lands:

- Clearing vegetation for agricultural purposes can permanently change the hydrology of karst areas, and lead to soil erosion and sedimentation problems in karst groundwater, particularly with the removal of tree stumps and root masses. (The typically deeper soils associated with lower elevation karst areas can be easily transported by surface runoff into the subsurface through sinkholes, sinking streams or cave entrances).
- Livestock can add to the problems of soil erosion and groundwater contamination on karst areas by destabilizing sinkhole sideslopes, eroding streamside banks, and depositing animal waste into streams.
- Pumping irrigation water from surface streams and karst aquifers, or draining wetlands, can lower the water table and accelerate sudden sinkhole formation and other collapse features.
- Sinkholes plugged with eroded soils and debris can lead to infilling with water and occasional flooding of range lands, particularly during high rainfall events and spring runoff.
- Due to rapid transit times and a lack of natural filtering and cleansing mechanisms, karst groundwater systems are highly susceptible to contaminants and pollutants, such as agricultural chemicals.

Best Management Practices

The following best management practices are recommended:

- When clearing land for pasture, follow the road building and timber harvesting best management practices as outlined under Harvesting Operations (Section VIII).
- Sinkholes should not be used as dumping sites for refuse, animal waste, carcasses, or agricultural chemicals.
- Keep agricultural chemical applications (fertilizers, pesticides) away from karst reserves and other areas where they could be washed into karst groundwater.
- Keep livestock away from the edges of cave entrances, sinkholes, and sinking streams with fencing or other means to prevent sideslope erosion and groundwater contamination from sediment transfer and livestock waste.
- For operations involving large numbers of livestock, buildings, such as dairy barns or feed lots, should be located away from areas that contribute to karst groundwater. Use settling ponds or vegetation strips to filter animal waste, where appropriate.