Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia

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Preface

The *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* describes provincial standards and procedures for conducting karst inventories and deriving karst vulnerability ratings. These processes are designed to be used in conjunction with the karst management recommendations outlined in the *Karst Management Handbook for British Columbia* (B.C. Ministry of Forests 2003).

This document builds upon the recommendations and proposals presented in *A Preliminary Discussion of Karst Inventory Systems and Principles (KISP) for British Columbia,* Research Program Working Paper 51/2000 (Stokes and Griffiths 2000). The KISP document was widely reviewed by national and international karst experts, industry, and staff from the Ministry of Forests and the Ministry of Environment, Lands and Parks.

The original version of these standards and procedures was released in January 2001. This second version primarily incorporates changes to the procedures for conducting karst field assessments, which are karst inventories conducted at the stand or cutblock level. These revisions are largely based on practical field experience and user feedback gained through operational use of the 2001 standards and procedures.

It is anticipated that additional revisions may be required once the RIC standards become more widely used across the province. Future revisions will again be guided by operational experience and user feedback to ensure that the standards and procedures apply effectively to karst areas in all parts of British Columbia.

Abstract

This report describes standards and procedures for conducting karst inventories and vulnerability assessments in British Columbia. The information provided here was developed for the Resources Information Standards Committee (RISC), a multi-agency committee responsible for establishing standards for natural and cultural resource inventories.

Karst inventories can be conducted at three levels: 1) the reconnaissance-level inventory; 2) the planning-level inventory and vulnerability potential mapping; and 3) the karst field assessment (KFA) and vulnerability assessment. The three levels of inventory provide a filtered approach to evaluating karst terrain, with each level having increased requirements for data collection and evaluation.

Reconnaissance-level karst inventory work for the entire province of British Columbia was completed in 1999. The result of this work is a set of 87 map sheets (1:250 000 scale) outlining those areas in the province that have the potential for karst development. These maps can be used to assist with strategic planning and for directing more detailed karst inventories.

Planning-level karst inventories are used to obtain a general sense of the karst attributes for an area of interest at the landscape level. This information can be used to assist resource planning, provide data for karst vulnerability potential mapping, and identify areas that require a more detailed KFA.

The planning-level procedure describes an office phase and a field phase. During the office phase, all available information for the area of interest is collected and compiled. There are six major field tasks associated with a planning-level inventory: 1) bedrock geological mapping; 2) karst mapping and evaluation of vulnerability potential; 3) identification of significant surface karst features and hydrological features; 4) determination of karst catchment and hydrology; 5) identification of karst flora/fauna and associated habitats; and 6) identification of geomorphic hazards.

Rating planning-level karst polygons for vulnerability potential is a qualitative evaluation based on: 1) the primary attributes of epikarst development, surface karst feature density, and subsurface karst potential; 2) the secondary attributes of surficial material type and thickness, bedrock type and proportion, and karst micro-topography; and 3) the tertiary attributes of slope class, drainage class, geomorphic processes, and other surface expressions. The presence of unique or unusual flora/fauna or associated habitats can be used to increase the vulnerability potential rating of some polygons.

Karst field assessments are carried out at the site level to obtain detailed information on karst resources within and adjacent to an area of proposed development, and to assess the vulnerability of the karst unit. Where caves are encountered, subsurface examination and mapping are also required. The information collected during a KFA is used to apply suitable forest practices as outlined in the *Karst Management Handbook for British Columbia* (B.C. Ministry of Forests 2003).

Data from reconnaissance-level and/or planning-level karst inventories, along with any other available information on the karst unit, are reviewed during the office stage of a KFA to help direct field activities. The major karst attributes assessed during a KFA include: karst unit boundaries; surface karst features; epikarst sensitivity; surface karst sensitivity; karst roughness; streams and hydrology; subsurface karst potential; and unique or unusual karst flora and fauna.

The karst vulnerability assessment process at the KFA level is a four-step procedure that determines a vulnerability rating (low, moderate, high, very high) for an identified polygon. The process considers three major criteria: 1) epikarst sensitivity; 2) surface karst sensitivity; and 3) subsurface karst potential. The procedure also allows for the integration of three modifying factors: 1) fine-textured, erodible soils; 2) karst roughness; and 3) unique or unusual flora/fauna and/or habitats.

Acknowledgments

The Government of British Columbia provides funding of the Resources Information Standards Committee work, including the preparation of this document. The Resources Information Standards Committee supports the effective, timely and integrated use of land and resource information for planning and decision making by developing and delivering focussed, cost-effective, common provincial standards and procedures for information collection, management and analysis. Representatives to the Committee and its Task Forces are drawn from the ministries and agencies of the Canadian and the British Columbia governments, including academic, industry and First Nations involvement.

The Resources Information Standards Committee evolved from the Resources Inventory Committee which received funding from the Canada-British Columbia Partnership Agreement of Forest Resource Development (FRDA II), the Corporate Resource Inventory Initiative (CRII) and by Forest Renewal BC (FRBC), and addressed concerns of the 1991 Forest Resources Commission.

For further information about the Resources Information Standards Committee, please access the RISC website at: http://srmwww.gov.bc.ca/risc/.

This project was initiated by Gerry Still (Research Branch, Ministry of Forests), and was subsequently managed by Steve Chatwin and Dan Hogan (Research Branch). Elizabeth Easton (Research Branch) assisted in coordinating the project. The principal contributors to the document were Tim Stokes (Terra Firma Geosciences Services), Paul Griffiths (Cave Management Services), Steve Chatwin (Research Branch, Ministry of Forests), and Bill I'Anson.

Many people assisted directly with the project. Thanks are extended to members of the Karst Management Working Group for their valuable input (in alphabetical order): Hugh Bomford (Canadian Forest Products Ltd.), Peter Bradford (Forest Practices Branch), Cam Brady (Port McNeill Forest District), Charlie Cornfield (Campbell River Forest District), Bob Craven (Western Forest Products Ltd.), Stu Ellis (Canadian Forest Products Ltd.), Gerry Fraser (Western Forests Products Ltd.), Laura Friis (Ministry of Water, Land and Air Protection), Doug Herchmer (Vancouver Forest Region), Dan Hogan (Research Branch), Bill Marshall (Forest Practices Branch), Hal Reveley (Vancouver Forest Region), and Gerry Still (Research Branch).

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1.0 Introduction

1.1 Objectives and Approach

Karst inventory and vulnerability assessment standards and procedures for British Columbia are described in this document. The procedures are based on the recognition that karst terrain is a sensitive and valuable resource that can be highly susceptible to disturbances, such as those associated with timber harvesting and road construction (B.C. Ministry of Forests 1997; Stokes and Griffiths 2000). As a result, the integration of karst management with forest development requires an inventory process that accurately identifies areas of karst terrain and assesses the inherent vulnerability of the karst system.

Three distinct levels for conducting karst inventories and vulnerability assessments are described:

- the reconnaissance-level inventory (typically at 1:250 000 map scale);
- the planning-level inventory and vulnerability potential mapping (typically at 1:20 000 or 1:50 000 map scales[1]); and
- the karst field assessment[2] (KFA) and vulnerability assessment (typically at 1:5000 or 1:10 000 map scales).

These three levels of inventory provide a filtered approach to evaluating karst terrain — beginning at the reconnaissance level and progressing downward through an intermediate planning level and finally to the KFA. Each level has increasing requirements for data collection and evaluation.

The karst inventory and vulnerability assessment process is summarized in Figure 1.1.

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1 The planning-level inventory procedure was developed and field tested based on a 1:20 000 map scale; however, the same principles and procedures can likely be applied at other appropriate scales, although this has not been field tested.

2 To conform with Forest Practices Code terminology, a karst inventory completed at the cutblock level (1:5000 or 1:10 000 scales) is referred to as a "karst field assessment" or a KFA.

Reconnaissance-level (1:250 000) inventory and karst potential maps with polygons evaluated for:
Criterion #1 – Primary, **S**econdary, or **T**ertiary likelihood for karst-forming bedrock to occur within a specific geological unit or polygon.
Criterion #2 – High, **M**oderate, or **L**ow intensity of karst development within a particular type of karst-forming bedrock.
Criterion #3 – the known presence of caves, caves and major surface karst features, or just major surface karst features (**-c, -ck,** or **-k**, respectively).
For details see Figure 2.1

#1 – If no previous information on karst within the area or bedrock unit exists, complete a regional planning-level inventory. **#2** – If karst is known to occur within an area or bedrock unit based on previous field work or karst inventories, complete a detailed planning-level karst inventory and vulnerability potential mapping. **#3** – If only a small area of concern exists, complete a karst field assessment (KFA) and vulnerability assessment.

A planning-level inventory is primarily comprised of six tasks:
Task 1 – Bedrock geological mapping.
Task 2 – Karst mapping and evaluation of vulnerability potential.
Task 3 – Identification of significant surface karst features and hydrological features.
Task 4 – Determination of karst catchment and hydrology.
Task 5 – Identification of karst flora/fauna and associated habitats.
Task 6 – Identification of geomorphic hazards.
A regional planning-level karst inventory is used to confirm the presence and extent of the karst unit; primarily focusing on Tasks 1, 3, and 4.
A detailed planning-level karst inventory and vulnerability potential mapping applies Tasks 1 to 6.
For details see Figure 3.1

#4 – After completing a regional planning-level inventory, decide whether to: i) do no further work, ii) complete a detailed planning-level inventory and vulnerability potential mapping, or iii) complete karst field assessments in selected areas. **#5** – After completing a detailed planning-level karst inventory, polygons with moderate, high, or very high vulnerability potential ratings require further evaluation at the KFA level.

Karst field assessment (KFA) and vulnerability assessment. Delineate karst unit boundaries and KFA boundaries. Assess karst attributes including: surface karst features, epikarst sensitivity, surface karst sensitivity, karst roughness, streams and hydrology, subsurface karst potential, and unique or unusual karst flora/fauna and/or habitats. Complete the four-step vulnerability assessment procedure and rate karst polygons for vulnerability. Compile map and report with a description of karst attributes, vulnerability ratings, and management recommendations.
For details see Figure 4.1

Figure 1.1. **Summary of karst inventory standards and vulnerability assessment procedures for British Columbia.**

Karst vulnerability methodologies can be applied at both the planning level and the KFA. The goals of these methodologies are to analyze data from the respective inventory levels and stratify the karst landscape (including its subsurface component) into polygons of similar karst vulnerability.[3] At the planning level, karst mapping is carried out whereby polygons are drawn and rated for karst vulnerability potential.[4] These polygons highlight the most dominant karst vulnerability potential ratings (low, moderate, high, or very high) within the polygon. Information on karst vulnerability potential at the planning level is used for both resource planning and to direct further inventory work.

At the KFA level, detailed karst vulnerability assessments are carried out using a four-step procedure. Once again, four qualitative karst vulnerability ratings can be determined—low, moderate, high, and very high. However, the polygons are smaller and more refined (due to more field checking) than at the planning level. The vulnerability ratings at the KFA level are used to guide forest harvesting and road construction recommendations, as outlined in the *Karst Management Handbook for British Columbia* (B.C. Ministry of Forests 2003).

A fundamental concept underlying the karst inventory and vulnerability assessment process is that the karst landscape be treated as a three-dimensional system, as opposed to a collection of discrete surface features that may, or may not, be connected to subsurface openings or caves. This system approach recognizes that karst operates as a holistic unit, whereby changes to conditions at the surface can influence conditions below the surface (e.g., heavy rainfall at the surface can lead to subsurface flooding). The connectivity or openness of a karst system is a critical factor controlling the degree and speed of changes that can occur between various components of the system (e.g., water or air transfer between the surface and subsurface).

In a broader sense, this system approach is also intended to include all components of the karst ecosystem,[5] with not only its distinct geological, geomorphological, and hydrological characteristics, but also (as much as practically possible) other attributes, such as karst biota and air exchange. Most of the karst inventory and vulnerability assessment procedures outlined in this document are applied at the surface of the karst system; however, the subsurface component of karst is also considered. Where caves or other underground cavities are encountered, subsurface investigation and mapping is required to determine their significance and orientation with respect to the surface. This information is then used in the application of specific surface management practices.

Much of the work used to develop the procedures in this document is based on a technical report titled *A Preliminary Discussion of Karst Inventory Systems and Principles (KISP) for British Columbia* (Stokes and Griffiths 2000). Testing of the proposed karst inventory and vulnerability assessment methodologies outlined in the KISP document began in 1999 when digital reconnaissance-level (1:250 000 scale) karst potential maps for the entire province of

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[3] Karst vulnerability is defined as "the susceptibility of a karst ecosystem to change, and is considered to be a function of its inherent characteristics and sensitivity."

[4] Karst vulnerability potential is defined as "the likelihood for a particular vulnerability rating to occur within a specific planning-level polygon" (e.g., a planning-level polygon with a moderate vulnerability potential would likely include predominantly moderate vulnerability areas with lesser amounts of low or high).

[5] A karst ecosystem is defined as "a functional unit consisting of all living and non-living physical and chemical elements of the karst environment that are linked through nutrient cycling and energy flow."

British Columbia were generated (Stokes 1999). During 1999 and 2000, karst inventory field trials were carried out at the planning and KFA levels to test and refine the proposed methodologies. The field trials were held at five sites—two on Vancouver Island (Extravagant Creek and Tashish River), two on the mainland (Chetwynd area and Cody Caves), and one on the North Coast (Chapple Inlet).

1.2 Karst Processes

Karst is a distinctive topography that results from the dissolving action of water on soluble bedrock (usually limestone, dolomite, marble, and, to a lesser extent, gypsum). This dissolving action produces a landscape characterized by features such as epikarst, vertical shafts, sinkholes, sinking streams, springs, complex subsurface drainage systems, and caves. The unique features associated with karst landscapes result from a complex interplay among geology, climate, topography, hydrology, and biological factors over long time scales. Further details on karst-forming processes can be found in a number of well-recognized scientific texts, such as Ford and Williams (1989), White (1988), and Jennings (1985). General issues related to the sensitivity of karst can be found in White et al. (1995), Kiernan (1990), and Harding and Ford (1993). In British Columbia, more recent work on forested karst terrain includes studies by Stokes (1996), B.A. Blackwell and Associates (1995), Stokes and Griffiths (2000), and Chatwin (1999).

1.3 Distribution of Karst in British Columbia

Karst is known to occur in all of British Columbia's forest regions, but has been well documented only in a limited number of locations (e.g., Vancouver Island). Carbonate bedrock underlies approximately 10% of British Columbia and provides an extensive area for potential karst development. The level of karst development across the province is highly variable due to the great range of bedrock types, physiography and biogeoclimatic settings. However, some generalizations and comparisons can be made to other parts of the world so that the overall significance of British Columbia's karst can be considered.

Much of the karst in British Columbia has developed in mountainous terrain with high rainfall and hydraulic heads that allows for extensive recharge and discharge of waters. Glaciation has played a major role in exposing, eroding, and burying earlier-developed karst. Extensive areas of carbonate in alpine karst areas occur along the Rocky Mountains, particularly at the southern end. These are similar to the well-studied tracts of karst in the European Alps and the Pyrenees. Well-developed karst areas associated with temperate rainforest occur in the significant carbonate units of Vancouver Island, and in smaller areas along the North Coast (e.g., Chapple Inlet) and in the Queen Charlotte Islands. These temperate rainforest karst areas are comparable to those found in New Zealand, Tasmania, and Chile. Karst associated with interior forests in the Purcell Mountains (e.g., Cody Caves and Namiku Caves) form steep and narrow bands that have similarities to the "stripe karst" of northern Norway. Less well-known areas of karst are reported in northwest British Columbia (e.g., along the Stikine and Taku rivers) and in northeast British Columbia (e.g., near Chetwynd and Prince George). Karst in the Interior Plateau (e.g., near Williams Lake) is the least known, and could be equivalent to that found in the foothills of the Slovenian Alps. Extensive glacial materials found in the Interior likely mask significant areas of karst terrain, with the karst exposed only in alpine or subalpine locations. The distribution of karst in British Columbia is further detailed in the reports of Stokes and Griffiths (2000) and Stokes (1999).

2.0 Reconnaissance-level Karst Potential Mapping and Inventory

The purpose of reconnaissance-level karst potential[6] maps is to identify areas of likely karst development to assist with strategic planning (e.g., higher level plans, land use plans, TFL management plans), and to direct more detailed karst inventories where required. Reconnaissance-level (1:250 000 scale) karst potential maps covering all of British Columbia were produced in 1999 (Stokes 1999). The project was an office-based exercise that included an analysis of 1:250 000 digital bedrock geology data (the B.C. Geological Survey and the Geological Survey of Canada), and information on known cave and karst occurrences in British Columbia. Approximately 7568 polygons were evaluated for karst potential, covering 87 NTS map sheets (1:250 000 scale).

Two criteria were used to evaluate karst potential within a particular polygon. Criterion #1, the likelihood of karst forming or soluble bedrock (e.g., limestone, dolomite, or gypsum) occurring within a unit (or map polygon), was evaluated by estimating the proportion of soluble bedrock and rating it as one of three categories—Primary (P) ≥50%, Secondary (S) 20–49%, or Tertiary (T) 5–19%. Criterion #2, the intensity of karst development in a particular type of soluble bedrock, was determined for each map polygon using four principal attributes that are important controlling factors for karst development—chemical purity, bedrock lithology, topographic position, and unit thickness/continuity.[7] Data for each of these attributes were obtained, categorized, and placed into a numerical algorithm, which weighted the attributes from the most important (chemical purity) to the least important (unit thickness/continuity). Numerical values from the algorithm were then qualitatively ranked as high (H), moderate (M), or low (L) for their intensity of karst development. A third criterion —Criterion #3—the known occurrence of caves or major surface karst features,[8] was also included on the karst potential maps. However, subsequent evaluation of this procedure indicated that Criterion #3 data should not be directly included in the karst potential maps, but rather used as a separate layer in the mapping system (see Stokes 1999).

The methodology used to compile the reconnaissance-level karst potential maps is summarized in Figure 2.1.

[6] The concept of “karst potential” is used to provide an indication of where karst might occur and what level of karst development might be anticipated.

[7] There are other important factors that control karst development (e.g., secondary porosity). However, this information was not available at the scale of mapping and/or level of data collection.

[8] Major surface karst features can be considered as any single, large feature or recognizable group of meso-scale karst features (such as sinkholes, swallets, karst bridges, karst canyons, or cave entrances). They do not include micro- or small-scale solution runnels or fractures apparent on individual outcrops.

Generation of reconnaissance-level karst potential polygons from 1:250 000 digital bedrock data from the B.C. Geological Survey and the Geological Survey of Canada.

Evaluation of each karst potential polygon for:
Criterion #1 – the likelihood of karst-forming bedrock to occur within a specific geological unit or polygon.
Criterion #2 – the intensity of karst development within a particular type of karst-forming bedrock.
Criterion #3 – the known presence of caves or major surface karst features.

Criterion #1 – based on an estimate of the percentage of soluble bedrock within a unit.
Primary (P): ≥50% soluble bedrock, **S**econdary (S): 20–49% soluble bedrock, and **T**ertiary (T): 5–19% soluble bedrock.

Criterion #2 – determined from a weighted numerical algorithm that includes four primary attributes related to karst development: chemical purity (P), bedrock lithology (BL), topographic position (TP), and unit thickness/continuity (UT). Each map polygon is given a numerical rating from 1 to 5 for each of the primary attributes.

$$\text{Criterion \#2} = (4 \times P) + (3 \times BL) + (2 \times TP) + (UT)$$

From the numerical values, qualitative ratings of High (H), Moderate (M), and Low (L) are derived for likely intensity of karst development, whereby High is ≥40, Moderate is 25–39, and Low is ≤24.

Criterion #3 – the confirmed presence of caves or major karst features is used to highlight areas of known karst development.

Final product: 1:250 000 maps with shaded polygons for Criterion #1 (P, S, or T) and Criterion #2 (H, M, or L) and labelled c, -ck, and -k, for known caves, known caves/major surface karst features, and known major surface karst features. Note: it is recommended that known cave/karst features be separated from the karst potential mapping information.

Prior to determining specific planning-level or karst field assessment (KFA) requirements for a site using the karst potential maps, some form of on-site karst information is required, either from field work or previous karst inventories. Karst potential maps provide an indication as to the likely extent of karst units and the possible intensity of karst development, but have some significant limitations and should be used with caution.

No previous information on karst within the area/bedrock unit. Complete a regional planning-level inventory to confirm the presence and extent of karst. ***See Figure 3.1.***

Karst known to occur within the area/bedrock unit from previous field work or karst inventories. Complete a detailed planning-level karst inventory and vulnerability potential mapping, or, if only a small area of interest, complete a karst field assessment (KFA) and vulnerability assessment. ***See Figure 3.1.***

Figure 2.1. **Methodology used to compile reconnaissance-level (1:250 000 scale) karst potential maps and inventory data for British Columbia, with links to the planning-level inventory and the karst field assessment.**

Prior to the initiation of any karst inventory work in a particular area, it is recommended that the reconnaissance-level karst potential maps and inventory data be examined. These maps are available in Arc-Info format and can be readily incorporated into any GIS. The Arc-Info format provides boundaries for the karst potential polygons and is linked to a database with karst attribute and rating information. Spreadsheets for the karst attribute and rating data are available in Excel (.xls) format, and can be linked to hard-copy maps derived from plot files. The Arc-Info files, Excel spreadsheets, and plot files are available through the Ministry of Forests, Research Branch, in Victoria (http://www.for.gov.bc.ca/ftp/Branches/Research/external/!publish/karst/). The information also includes a report covering the scope, methodologies, limitations, and findings of the project (see Stokes 1999).

An evaluation of the reconnaissance-level karst potential maps was carried out during the karst inventory field trials. During the field trials, it was apparent that the karst potential maps had varied success in their ability to accurately portray the level of karst development in different areas. Where the unit was known to contain karst from previous field work (e.g., the Quatsino Formation of Vancouver Island), the Criteria #1 and #2 data were generally reliable. Where little to no field information was available on the bedrock unit (e.g., the Palliser Formation of the Rocky Mountains), the ratings, particularly Criterion #2, were less precise. However, one advantage of the karst potential maps is that once a unit has been examined in the field, it is then possible to cautiously extrapolate ratings to adjacent areas. Overall, the karst potential maps provide a useful preliminary tool in the initial stages of karst evaluation; however, they have some severe limitations and should be treated accordingly. Continual updating and refinement of these maps is essential if they are to be used successfully.

The main limitations of the reconnaissance-level karst potential maps are:

- the Criteria #1 and #2 ratings can be unreliable in areas not field checked for karst;
- karst can occur outside the indicated polygons (e.g., as small lenses/pods or in thinly bedded units with striped karst [D.C. Ford, pers. comm., 1999]);
- the 1:250 000 polygon boundaries are not reliable at more detailed scales; and
- not all known cave/karst information was included on the maps due to time/cost limitations for the project (see Stokes 1999).

The karst inventory field trials highlighted a number of refinements that could be incorporated into the reconnaissance-level karst potential mapping. These refinements include:

- separating out the known cave and karst information;
- modifying the Criterion #2 rating to consider the broad physiographic regions, biogeoclimatic zones, and glacial cover in British Columbia;
- altering the Criterion #1 categories to highlight only carbonate units that have >80% soluble bedrock; and
- resolving inconsistencies in the original bedrock data for certain map sheets.

Overall, the reconnaissance-level karst potential maps can be considered a good starting point as background information prior to completing planning-level inventories or KFAs. The Criteria #1 and #2 ratings provide a general idea as to what might be anticipated for a soluble bedrock unit or map polygon, but these ratings can, in practice, be one or possibly even two categories out. Field checking or prior knowledge of karst conditions at a site is crucial to help determine the requirement for planning-level inventories or KFAs.

3.0 Planning-level Karst Inventory

3.1 Goals, Objectives, and Approach

The primary goals of the planning-level karst inventory are to provide data for mapping karst vulnerability potential, to assist with landscape-level planning at the 1:20 000 or 1:50 000 scale (e.g., Tree Farm Licences), and to help direct karst field assessments at the stand or cutblock level. From a long-term planning perspective, the information from planning-level inventories can provide an indication of the level of effort associated with operating on certain karst areas, and assist with timber supply estimates by identifying areas of karst where harvesting constraints may apply (e.g., very high vulnerability potential areas).

The principal objectives of the planning-level inventory are:

- to delineate the geological boundaries of the karst unit and its three-dimensional distribution;
- to determine the regional extent of the karst catchment[9];
- to locate and identify major surface karst features, cave entrances, and evidence of epikarst development;
- to consider the potential for subsurface openings;
- to define karst polygons and rate them for karst vulnerability potential;
- to identify the likely presence of any unique karst-specific biota or related habitat; and
- to identify any geomorphic hazards that could potentially affect the karst unit.

Initiation of a planning-level inventory should occur 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 are identified in or around an area of proposed development.

There are two types of planning-level inventory, depending on how much is known about the karst in the area of interest:

1) Regional planning-level inventory – A regional planning-level inventory would typically be carried out in areas where little to no prior knowledge of karst development is available. However, karst may be suspected from either unconfirmed field reports or reconnaissance-level karst potential maps. The main objective of a regional planning-level inventory is to evaluate the presence and extent of karst within an area (or bedrock unit) to help determine the need for any further inventory work. A regional planning-level inventory would focus primarily on Tasks 1, 3, and 4 as outlined in Section 3.3.

2) Detailed planning-level inventory – A detailed planning-level inventory is used to evaluate areas of karst that are either known or anticipated. One of the primary objectives of a detailed planning-level inventory is to stratify the karst landscape into polygons of different vulnerability potential. A detailed planning-level inventory would include all of Tasks 1 to 6 as outlined in Section 3.3.

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[9] A karst catchment differs from a topographic catchment in that it can include cross-divide connections through subsurface drainage paths.

Prior to initiating any planning-level inventory work, the decision must be made as to whether to conduct a regional or detailed planning-level inventory based on previous knowledge and/or experience with karst conditions in the area of interest (see Figure 3.1 for a summary of the planning-level methodology). If the decision is made to conduct a regional planning-level inventory, there are three possible outcomes regarding the requirement for further inventory work:

1. no additional karst inventory is required for the area;
2. a detailed planning-level karst inventory is required for all or part of the area; or
3. a KFA is required for specific parts of the area (see Section 4.0).

One or more combinations of these options could be employed, depending on the size and complexity of the karst unit. The decision whether further inventory work is required or not should consider the anticipated activities in the area. For example, if a series of roads and cutblocks is anticipated over a large, well-developed karst unit, a detailed planning-level inventory would likely be warranted. However, if only one cutblock is planned near a small karst unit, it may be appropriate to go directly to a KFA, rather than completing a detailed planning-level inventory.

3.2 Initial Office Work and Data Compilation

As a first step in completing a regional or detailed planning-level inventory, all available information for the area of interest is collected and compiled, and a series of working maps developed. An example of existing information that should be gathered includes:

- detailed bedrock geology maps (1:50 000 scale or larger);
- surficial geology maps (1:50 000 scale or larger);
- detailed topographic information (1:50 000 and 1:20 000 scale);
- air photos (both recent and historical, colour and/or black and white);
- satellite imagery data or other remote sensing information, if available;
- terrain stability mapping (1:20 000 scale);
- karst inventory maps and reports, cave maps and related information, forest cover maps, forest development plans;
- recreation maps with K00 (or L5) polygon designations;
- terrestrial ecosystem and fish inventory maps; and
- records on any unique karst-related biota or habitat.

All relevant karst information (e.g., unit boundaries, identified features) is transferred onto a base map. This base map is usually a digital TRIM map and would generally display contours, streams, coastlines, and lakes. Geological boundaries for the karst units are taken from detailed (1:50 000 scale or larger) bedrock maps and plotted with the appropriate line work (e.g., solid line for defined, dashed for approximate, and dotted for assumed.) (Directly transferring polygon boundaries from the 1:250 000 reconnaissance-level karst potential maps to the 1:20 000 maps should be avoided where possible because of likely errors due to differences in scale.) Data for karst polygon boundaries can also be obtained from recreation, terrain, or other maps, but may be of varying reliability.

Initial Office Work and Data Compilation

i) Collect available geology, terrain, and forest cover maps, topographic data, recent air photos, previous karst inventory reports/data, and other applicable information.
ii) Examine reconnaissance-level (1:250 000 scale) karst potential maps and assess information.
iii) Develop a base map at the required scale, and delineate likely boundaries of the karst unit from the best available and most detailed (1:50 000 scale or larger) bedrock geological maps.
iv) Develop concepts on the three-dimensional distribution of the karst unit using simple cross-sections and/or block diagrams.
v) Examine the extent of the karst catchment and indicate boundaries and types of catchment areas – topographic, adjacent, or adjoining.

Decision #1: *What approach should be taken for the area—a regional or detailed planning-level inventory?*

No previous information on karst within the area/bedrock unit.

Complete a regional planning-level inventory to confirm the presence and extent of karst. (Focus primarily on Tasks 1, 3, and 4.)

Karst known or anticipated to occur within the area based on previous field work or karst inventories.

Complete a detailed planning-level inventory and vulnerability potential rating to stratify the karst landscape. Apply Tasks 1 to 6.

Field Tasks:
Task 1 – Bedrock geological mapping.
Task 2 – Karst mapping and evaluation of vulnerability potential.
Task 3 – Identification of significant surface karst features and hydrological features.
Task 4 – Determination of karst catchment and hydrology.
Task 5 – Identification of karst flora/fauna and associated habitats.
Task 6 – Identification of geomorphic hazards.

Decision #2: *After completing a regional planning-level inventory, there are three possible outcomes for additional inventory work.*

1. No further inventory work required.

2. Complete a detailed planning-level inventory and vulnerability potential rating.

3. Complete a karst field assessment (KFA) and vulnerability assessment for specific parts of the area of interest.

Decision #3. *After completing a detailed planning-level inventory and vulnerability potential rating, the karst unit is stratified into polygons with low, moderate, high, or very high potential ratings.*

Complete a KFA for polygons with moderate, high, or very high vulnerability potential ratings.

Figure 3.1. **Methodology for the planning-level karst inventory.**

Detailed bedrock geology maps (1:50 000 scale or larger) can be used to determine the likely three-dimensional distribution of karst units by applying basic geological knowledge on bedrock lithology types and structure (e.g., bedding dip, folds, and faults). Simple geological cross-sections can be constructed across the area of interest, or more complex block models can be developed. Knowing the three-dimensional distribution of the karst unit and dominant structural controls can greatly assist in understanding the likely extent of the karst hydrological system and the orientation of cave passages and subsurface conduits (e.g., preferential development of a cave system along bedding planes).

Initial indications on the regional extent of the karst catchment are obtained from information on the distribution of the karst unit, topographic maps, and any known karst features. The limits of the karst unit of interest and any nearby karst units are plotted onto the base map along with lines indicating the topographic catchment divides. Upslope karst and non-karst terrain within the same topographic catchment that contributes water to the karst unit of interest is part of the karst catchment and is termed the “adjacent karst catchment.” Because of the subsurface flow characteristics of karst, contiguous karst units in different topographic catchments, along with their respective upslope non-karst catchments, can also contribute water to the karst unit of interest. These are termed “adjoining karst catchments.” The limits of the various karst catchment types are drawn on the base maps and indicated as to whether they are topographic, adjacent, or possibly adjoining (see Figure 3.2). This information will provide the first step in determining what are the likely issues of concern with respect to the karst hydrological system, and may also provide some indication as to whether dye tracing is required to help determine subsurface flow patterns (see Section 3.3.4). Where large karst catchments are present, 1:50 000 scale base maps may be useful.

Any previous information on likely unique or unusual flora, fauna, or habitats within a karst area of interest should be compiled for the project area. Initial information might be obtained from existing inventory reports or government agencies (e.g., Ministry of Sustainable Resource Management, Conservation Data Centre). Details on likely fauna and flora habitats associated with karst are discussed in Section 3.3.5. A list of karst flora and fauna species, with particular emphasis on British Columbia, is provided in Tables A1 and A2 in Appendix A.

Satellite imagery data could be used at the planning level to assist with the mapping procedures. At present, coloured or black-and-white IRS satellite imagery data are available with a resolution of 5-m pixels, and can be plotted on maps with good clarity at scales up to 1:20 000. The more recent IKONOS satellite (launched in 1999) can provide data with a resolution of 1-m pixels, and can be plotted on maps up to 1:2500 scale (H. McLaughlin, pers. comm., 1999). The main advantage of the satellite imagery data is that they can readily provide current information for a site. Other advantages of satellite imagery data, compared to air photos, are that they are less expensive and available by the map sheet. Satellite imagery also has the potential for identifying karst units by enhancing various colour bandwidths to highlight changes in vegetation or site conditions. This approach has not been tested in the forested karst areas of British Columbia, but is worthy of consideration.

Light detection and ranging (LIDAR) has recently been used successfully in southeast Alaska to accurately map karst features through the forest canopy (J. Baichtal, pers. comm., 2000).

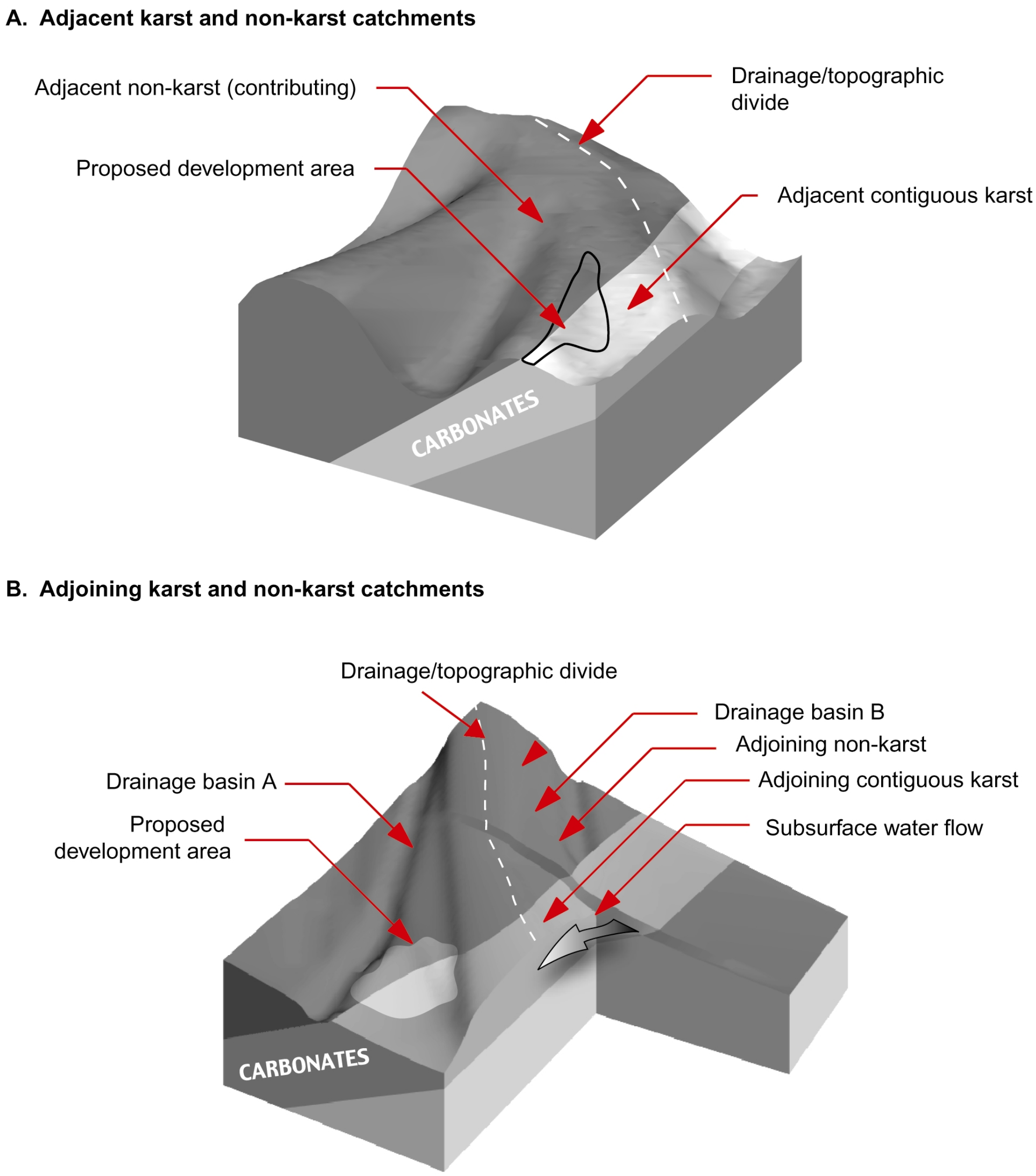

Figure 3.2. **Karst catchment hydrology and definitions.**

3.3 Required Field Work and Tasks

The key attributes to be located, identified, and measured during a planning-level inventory are provided in Appendix B.

Field work for the planning-level inventory can be divided into six tasks:

Task 1 – Bedrock geological mapping;

Task 2 – Karst mapping and evaluation of vulnerability potential;

Task 3 – Identification of significant surface karst features and hydrological features;

Task 4 – Determination of karst catchment and hydrology;

Task 5 – Identification of karst flora/fauna and associated habitats;

Task 6 – Identification of geomorphic hazards.

The amount of work required for each of these tasks in any particular area is highly variable, and depends on site conditions and the amount of existing information. For example, if detailed bedrock geology maps and previous surface karst feature data are available for a site, Tasks 1 and 3 would likely be reduced. However, if the only available bedrock geology maps are at 1:250 000 scale, bedrock mapping could form a major part of the work. Overall, Tasks 1, 2, and 3 are anticipated to be the principal tasks requiring most of the field time.

3.3.1 Task 1 – Bedrock geological mapping

Bedrock mapping is an integral and fundamental part of the planning-level inventory, as it entails determining the boundaries and extent of the karst unit. Where complex geological relationships are encountered, or where detailed bedrock mapping is unavailable, considerable field work may be required. Less bedrock mapping is required where the geology is relatively straightforward or where previous detailed mapping is available. Bedrock geological mapping should closely follow procedures outlined in *Specifications and Guidelines for Bedrock Mapping in British Columbia* (RIC 1996b). However, in many cases, detailed bedrock mapping and interpretation of the bedrock geology to standards required by the provincial government (e.g., B.C. Geological Survey) are not likely to be achieved, primarily due to time limitations in the field.

In general, bedrock mapping should focus on:

- determining the locations and types of geological contacts and relationships;
- the types and changes in bedrock lithology; and
- the main bedrock fault and fold structures.

Sufficient bedrock information should be obtained so that the surface and likely three-dimensional extent of the main karst-forming unit can be determined.

3.3.2 Task 2 – Karst mapping and evaluation of vulnerability potential

Karst mapping and evaluating vulnerability potential is one of the major tasks to be completed during a detailed planning-level inventory. This task involves the delineation of karst polygons, the collection of data on karst characteristics, and an evaluation of vulnerability potential. The purpose of this mapping procedure is primarily to stratify the karst landscape into polygons with similar karst attributes and characteristics. Many of the procedures and standards used for karst mapping are similar to those for terrain mapping (Howes and Kenk 1988; B.C. Ministry of Forests 1995; RIC 1996a). However, the fundamental concepts of karst mapping are based, as much as possible, on the distribution and variations of karst characteristics, rather than those of terrain. While many of the attributes considered for karst mapping are similar to those required for terrain mapping (e.g., surficial cover type/thickness, slope gradient, drainage), additional attributes specifically related to karst processes need to be collected, including information on epikarst development, surface karst feature density, and subsurface karst potential.

Preliminary karst polygon delineation

Prior to field work for karst mapping, the typing of suitable air photos[10] is used to delineate the boundaries for preliminary karst polygons. Many of the procedures for the selection, use, and interpretation of air photos are similar to those outlined in *Guidelines and Standards for Terrain Mapping in British Columbia* (RIC 1996a); likewise for the methods of defining polygons, delimiting polygon boundaries, and the usage of feature symbols. The geological boundaries of the anticipated karst units are transferred from available bedrock geology maps to the air photos as accurately as possible, followed by boundaries for the preliminary karst polygons. Successful boundary delineation of karst polygons from air photos can vary depending on the experience of the mapper, the presence of vegetation cover, and the intensity of karst development. Air photo interpretation of karst characteristics in lightly forested areas (e.g., subalpine slopes) and previously harvested sites is generally easier than in the denser canopies of coastal or interior forested karst. However, with careful stereoscopic examination, large surface karst features, disrupted drainage patterns, and changes in surface texture are commonly visible even within denser canopy areas. In previously harvested areas, historic air photos can be particularly useful, as the karst is more easily recognized before tree height and canopy closure obscure the ground surface.

The method for delineating karst polygons is somewhat similar to that for terrain polygons, whereby a specific area is delimited with similar processes and characteristics. Typically, terrain or karst polygons define a homogenous area with respect to adjacent polygons, and can be either simple, with one controlling attribute, or composite, with two or more controlling attributes. The best approach at a previously unknown site is to initially use terrain characteristics to develop preliminary karst polygon boundaries. However, as field work progresses, and additional data on karst attributes are collected, the polygon boundaries can be altered or modified to reflect the new information. A mapper familiar with karst processes should be able to rely on past knowledge of similar sites, and, in effect, develop karst analogue models based on the characteristics of the landscape. For example, in limestone of the Quatsino Formation of Vancouver Island, gentle, moderate-slope benches are more likely to contain surface karst features than are steep slopes. Preliminary karst polygons can initially be quite large, but are generally sub-divided one or more times during subsequent field work.

Field work methodologies and collection of karst data

In general, field work methodologies for karst mapping are similar to that for terrain mapping (refer to Section 7.0 in the *Guidelines and Standards for Terrain Mapping in British Columbia*). However, there are differences in the intensity of field checking, types of data collected, and the ways in which they are compiled. These differences and refinements are outlined below.

Karst processes and features have been categorized to a limited extent in the *Terrain Classification System for British Columbia* (RIC 1997), with a code for the karst process

[10] Either colour or black-and-white air photos are acceptable; however, newer photos are better so that recent features (e.g., forest roads/cutblocks) can be used for field orientation.

(-K) and a number of on-site symbols for certain karst features (e.g., sinkholes). However, karst data collection procedures required for karst mapping are much more detailed. Codes have been developed for epikarst development, surface karst feature density, subsurface karst potential, and bedrock type/proportion. A number of other additions/refinements have been made, such as codes for surficial material thickness, karst micro-topography, and on-site mapping symbols. Table 3.1 outlines headings in a data file that can be used in a spreadsheet to assist in the gathering of information, while Table 3.2 provides descriptions and categories for karst attribute data collected during field work. Karst mapping could, if desired, eventually be integrated into the *Terrain Classification System for British Columbia* (RIC 1997); however, for the present, it is suggested that it be kept as a stand-alone procedure until it has been further tested and applied in the field.

Table 3.1. **Descriptions of data file headings used for karst mapping and vulnerability potential ratings**

Polygon #	Number of polygon corresponding to map sheet.
Soluble Bedrock Unit	Name of soluble bedrock unit. Useful if more than one unit on map sheet.
Bedrock Type and Proportion of Soluble Bedrock in Polygon	Type of soluble bedrock and proportion anticipated in the polygon (see Table 3.2). For example, lsX-4 would indicate 50–80% limestone anticipated within the polygon.
Soluble Bedrock Confirmed in Outcrop	A Yes or No response as to whether soluble bedrock was encountered in the polygon during field work.
Surficial Material Type/Thickness	Use code as in *Terrain Classification System for B.C.*, except for addition indicated in Table 3.2.
Qualifying Descriptor	As in *Terrain Classification System for B.C.*, but could be used for karst micro-topography code in Table 3.3.
Geologic Processes	Use code as in *Terrain Classification System for B.C.*
Slope Gradient/Class	Use code as in *Terrain Classification System for B.C.*
Drainage	Use code as in *Terrain Classification System for B.C.*
Epikarst Development	Use code as in Table 3.2.
Surface Karst Feature Density	Use code as in Table 3.2.
Subsurface Karst Potential	Use code as in Table 3.2.
Vulnerability Potential Rating	Overall vulnerability potential ratings are provided for each polygon based on a qualitative evaluation of karst and terrain characteristics. These ratings are: L – Low, M – Moderate, H – High, and V – Very High.
Level of Field Evaluation	A rating is provided for each polygon to provide an indication as to the level of field examination carried out. L – Low: polygon not traversed; attributes determined from adjacent polygons and/or air photos, etc. M – Moderate: polygon traversed once. H – High: polygon traversed at least twice.
Comments	Any relevant comments that relate to the polygon. Could include comments on possible biota sites or significant surface karst features.

Table 3.2. **Planning-level karst mapping attributes and descriptions**

Bedrock Type and Proportion of Soluble Bedrock in Polygon ls – limestone, g – gypsum, d – dolomite X-1 – <10% soluble bedrock in polygon X-2 – 10–20% soluble bedrock in polygon X-3 – 20–50% soluble bedrock in polygon X-4 – 50–80% soluble bedrock in polygon X-5 – >80% soluble bedrock in polygon
Surficial Material Type and Texture as in the *Terrain Classification System for B.C.* (TCS-BC). (Note: apply symbol "O" for organic forest litter and descriptors for organic texture, regardless of depth, as this typically overlies well-developed karst surfaces.) **Qualifying Descriptors** as in the TCS-BC, could add descriptions for karst micro-topography **Drainage, Slope Class, and Geological Processes** as in TCS-BC
Surficial Material Thickness (slightly modified from the TCS-BC) x – very thin >2 cm < 20 cm and frequent bedrock outcrops s – shallow veneer 20–50 cm with common bedrock outcrops v – veneer 51–100 cm with a few outcrops b – blanket 101–200 cm and rare outcrops t – thick blanket >200 cm and no outcrops
Epikarst Development *u – Unknown epikarst development* Epikarst surface not visible or buried by thick surficial materials. *n – No apparent epikarst development* No observed solutional epikarst development on confirmed carbonate bedrock. *s – Slightly developed epikarst* Widely spaced (>2 m) solutional openings, less than an average of 0.5 m depth. *m – Moderately developed epikarst* Medium spaced (<1 m) solutional openings with an average of 0.5–1.0 m depth. *h – Highly developed epikarst* Closely spaced (<0.5 m) solutional openings with an average 1–2 m depth. *i – Intensely developed epikarst* Very closely spaced (<0.25 m) solutional openings typically >2 m depth.
Surface Karst Feature Density (Mesoscale dimensions >2 m and <20 m in size). *N – No karst features observed or anticipated on surface* No karst features due to absence of karst processes or mantling by thick soil deposits. *L – Low density of karst features* Few sinkholes, grikes, and cave entrances/shafts (1–5 features/ha). *M – Moderate density of karst features* Occasional sinkholes, grikes, and cave entrances/shafts (6–10 features/ha). *H – High density of karst features* Numerous sinkholes, grikes, solutional openings, etc. (>10 features/ha).
Subsurface Karst Potential *L – Low Potential* Normal drainage patterns, low hydraulic head, low relief. Subsurface openings not anticipated. *M – Moderate Potential* No known caves or cave entrances, but with adequate hydraulic head and site conditions suitable for subsurface opening development (e.g., bench with sinking streams on upslope karst unit boundary). *H – High Potential* Known caves / cave entrances, sinking streams, springs, and high hydraulic gradient.

The first type of information to be collected is bedrock unit name, bedrock type, and anticipated proportion of soluble bedrock (see Tables 3.1 and 3.2). The anticipated proportion of soluble bedrock can be used where the geological boundary of a karst unit is unclear (e.g., buried by surficial cover), or if the unit is comprised of pods/interbeds of soluble bedrock. In addition, a heading is included in Table 3.1 for a Yes or No response as to whether soluble bedrock was encountered within a polygon.

The symbols, terms, and codes for surficial material type and texture can be applied as they are for terrain mapping (see Howes and Kenk 1998); likewise for geological processes and associated sub-classes. Similarly, terrain drainage codes and slope classes can be used as described in *Guidelines and Standards for Terrain Mapping in British Columbia* (RIC 1996a). Two refinements are suggested for the surficial material thickness codes. The first is the addition of a shallow veneer code, (s) 20–50 cm for surficial material thickness, and the second is the addition of outcrop descriptors to each of the thickness codes (see Table 3.2). Another refinement is to ensure more common usage of the organic material code (O) for the forest litter overlying karst surfaces (see Table 3.2). Typically, in many coastal forested areas, this is the only material present on karst surfaces, and can be easily lost into vertical solutional openings in the epikarst during forestry activities. The identification of this material, its texture (e.g., fibric or misic), and thickness, at any depth, is therefore an important part of the data collection procedure.

Surface expression codes as outlined in the *Terrain Classification System for British Columbia* (RIC 1997) can be used for karst mapping, but are somewhat limited in their ability to describe the karst landscape. A series of mapping codes for karst micro-topography[11] was developed based on the karst inventory field trials (see Table 3.3). The micro-topography codes can be used to classify the general karst surface that is within the field of vision in forested terrain (e.g., 10–100 m). These codes can also be used for rating karst vulnerability potential, and can assist in forest development planning (e.g., by ensuring that roads are located away from identified areas of closely spaced hums and hollows).

Table 3.3. **Suggested mapping codes for karst micro-topography**

kc	– closely spaced karst hums and hollows (<50 m between hum centre points and typically >10 m in elevation between top of hums and base of depressions)
kh	– moderately spaced hums and hollows (>50 m and <100 m between hum centre points, and typically 5–10 m elevation difference between top of hums and base of depressions)
kw	– widely spaced hums and hollows (>100 m between hum centre points and <5 m elevation difference between top of hums and base of depressions)
kb	– karst bench and bluff complex (narrow linear bluffs and benches <50 m wide and too small to map as individual polygon)
ki	– irregular karst surface with numerous depressions (e.g., sinkholes)
km	– moderately irregular karst surface with occasional depressions (e.g., sinkholes)
ks	– slightly irregular karst surface with rare depressions (e.g., sinkholes)

Note: These codes have not been field tested, but were developed based on findings from karst inventory field trials. Further additions to these codes could be made to reflect local site conditions.

[11] Micro-topography, for the purpose of this procedure, is defined as small-scale topography within the field of vision in forested karst. Typically, this is in the order of >1–5 m change in elevation and >10–50 m in horizontal distance.

Categories for the principal karst-mapping attributes of epikarst development, surface karst feature density, and subsurface karst potential are outlined in Table 3.2. These categories were developed during the karst inventory field trials, and are intended to cover most of the karst characteristics encountered in forested areas of coastal and interior British Columbia. However, some minor refinements to these categories may be required to adjust to local conditions.

Determination of epikarst development is based on a visual estimation of the depth and frequency of vertical solutional openings. This can be done by referring to the descriptions for each of the epikarst development categories in Table 3.2, or by using a visual chart for determining epikarst development at the KFA level (refer to Figure 4.8).

Surface karst feature density is determined by estimating the number of surface karst features per hectare (by considering a 100 by 100 m square, or a circle with a radius of approximately 56.4 m). For the purpose of this procedure, surface karst features can include solutional openings (e.g., grikes), sinkholes, shafts, and cave entrances. These features must have one measurable surface dimension (length, width, diameter) greater than 2 m, but no dimension greater than 20 m. Typically, any features greater than 20 m should be plotted as an on-site symbol, and likely represent a "significant" feature (see Section 3.3.3). Surface karst feature density can be estimated using the descriptive categories provided in Table 3.2, or by using the visual chart for determining surface karst feature density at the KFA level (refer to Figure 4.10).

No subsurface evaluation, other than possibly a brief cave entrance examination, is anticipated during the planning-level inventory. Care should be taken to closely locate and geo-reference cave entrances and other openings to assist further inventories at the KFA level. The categories for subsurface karst potential (low, moderate, and high; see Table 3.2) are based on a combination of direct field observations and a general understanding of the likely karst processes at a site.

Procedure for vulnerability potential rating

The final stage of karst mapping at the planning level is the allocation of vulnerability potential ratings to karst polygons. This procedure is a qualitative evaluation of the karst and terrain characteristics of each polygon, and is based on some general guidelines (outlined below and in Table 3.4), but primarily relies upon the experience and judgement of the mapper completing the work. This approach is similar in concept to that used for deriving stability classes from 1:20 000 scale terrain mapping, and allows the mapper a certain level of professional flexibility. Four rating categories of vulnerability potential are used—low (L), moderate (M), high (H), and very high (V)—coinciding with the four vulnerability assessment categories used at the KFA level. (The differences between vulnerability potential ratings at the planning level and vulnerability assessments at the KFA level are highlighted in Section 1.1).

The process for determining vulnerability potential ratings is qualitative, and considers karst attributes in their relative order of importance—primary, secondary, and tertiary (see Table 3.4). Epikarst development, surface karst feature density, and subsurface karst potential are considered the primary attributes for determining vulnerability potential ratings. Secondary attributes that should be considered include surficial material type and thickness, bedrock type and proportion, and karst micro-topography. Tertiary attributes include slope class, drainage class, geomorphic processes, and other surface expressions.

Table 3.4. **Determination of planning-level vulnerability potential rating and order of attribute importance**

Primary Attributes	– epikarst development – surface karst feature density – subsurface karst potential
Secondary Attributes	– surficial material type and thickness – bedrock type and proportion – karst micro-topography
Tertiary Attributes	– slope class – drainage class – geomorphic processes – other surface expressions

In general, the highest rating category for a karst attribute (see Table 3.2) should be used to derive the overall vulnerability potential rating. For example, a karst polygon with slightly developed epikarst, a low density of karst features, and a high subsurface karst potential should receive a high vulnerability potential rating.

It is recommended that mappers develop a set of tabular criteria that are site-specific descriptions for each vulnerability potential rating (low, moderate, high, and very high). Examples of vulnerability potential ratings for typical karst terrain conditions in British Columbia are provided in Table 3.5.

The presence of unique or unusual flora/fauna or associated habitats can also influence the vulnerability potential ratings for some polygons. This is discussed further in Section 3.3.5.

In general, the unpredictable nature of karst formation processes requires considerable ground coverage of the karst polygons until the conditions are well characterized. The approach of the vulnerability potential mapping procedure is constrained, in part, by the anticipated end use, as this can influence the amount of detail and field checking required (see Table 3.6).

If the main focus of the mapping is to direct a KFA, field checking should focus on identifying the boundaries between low vulnerability potential polygons and the other categories of moderate, high, and very high, as all of the latter will require a KFA. Clumping of the moderate and high polygons in this case would be acceptable. Terrain survey intensity levels (TSILs) with 20–50% polygon coverage (TSIL C) or less, would likely cover the ground effectively in this situation.

If an additional purpose of the mapping is to assist forest development planning in the design of cutblocks and road layout, identification of the boundaries of very high vulnerability potential polygons would be important, as these areas are unlikely to be suitable for forestry activities. In this case, the mapping would require more field checking, with approximately 50–75% polygon coverage (TSIL B).

If another requirement of the mapping is to determine the amount of future ground searching for a KFA, it may be necessary to accurately differentiate the moderate and high vulnerability potential polygons. This would likely require 75–100% polygon coverage (TSIL A).

Table 3.5. **Examples of planning-level vulnerability potential ratings in forested karst terrain in British Columbia**

Vulnerability potential rating	Description of karst terrain conditions*
Low	Low vulnerability potential karst polygons 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 well-developed epikarst, and isolated surface karst features. A coastal British Columbia example of low vulnerability terrain could be a valley bottom with a very thick glacial till cover and evidence of epikarst development exposed only in road cuts, with no surface karst features apparent. An interior British Columbia example could include an exposed limestone or dolomite ridge, with a thin soil cover, and little to no epikarst development or surface karst features.
Moderate	Moderate vulnerability potential karst polygons could include a relatively wide range of terrain conditions. Such terrain conditions could include moderately well-developed to well-developed epikarst, with a thin soil veneer (<50 cm) and a low number (1–5/ha) of surface karst features. Alternatively, terrain conditions could include a blanket of soil, with slight to no epikarst development and a moderate number (5–10/ha) of surface karst features. In most cases, it would be anticipated that a moderate or possibly high potential for subsurface openings exists. An interior British Columbia example of this type of terrain would be a gentle to moderate sloping bench, with a blanket of till cover and little to no epikarst development, but with a significant number of sinkholes, swallets and springs.
High	High vulnerability potential karst polygons could include terrain with moderately well-developed to well-developed (1–2 m deep) epikarst, a high density (10–20/ha) of surface karst features, and a high likelihood for subsurface karst openings. An example of this type of terrain on coastal British Columbia could include a gentle sloping bench, with a thin till veneer exposing a distinct solutional epikarst surface that is interspersed with a number of surface karst features, including cave entrances. A series of sinking streams and swallets could also be present on the upper contact of the bench, confirming the presence of subsurface openings.
Very High	Very high vulnerability potential karst polygons can be anticipated to include terrain with a combination of well-developed epikarst (>1–2 m depth), numerous (>20/ha) mesoscale surface karst features, and known subsurface openings or caves. In this case, there would be a high level of connectivity between the surface and subsurface. An example of this type of terrain on 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 a subsurface system that has significant decorations and/or contains important habitat for cave fauna.

* This table provides descriptions and examples for various karst vulnerability potential ratings, and is based on experience within forested karst areas of British Columbia. It is not anticipated that the descriptions will cover all possible examples; however, they will provide some indication of the typical terrain and karst conditions that might be encountered.

Table 3.6. **Karst vulnerability potential ratings at the planning level and their likely uses and applications**

<table>
<tr><th rowspan="2">Karst vulnerability potential ratings at the planning level</th><th colspan="4">Uses and applications</th></tr>
<tr><th>1
Directing KFA needs</th><th>2
Strategic planning</th><th>3
Forest development planning (e.g., design of cutblock and road layout)</th><th>4
Anticipated KFA ground searching and cave inspections</th></tr>
<tr><td>Low</td><td>No KFA required</td><td rowspan="3">Development can likely proceed, but with some restrictions</td><td>Little modification to standard forest practices</td><td>Cursory ground search</td></tr>
<tr><td>Moderate</td><td rowspan="3">KFA required</td><td rowspan="2">Some to considerable modification to standard forest practices</td><td>Less intense ground search and possible cave inspections</td></tr>
<tr><td>High</td><td>Intense surface ground search and probable cave inspections</td></tr>
<tr><td>Very High</td><td>Development likely to be restricted</td><td>Highly specialized practices likely required</td><td>Highly detailed ground search and cave inspections</td></tr>
</table>

Example A. If the main applications of vulnerability potential mapping are 1 and 2, the field work should focus on identifying polygons with low and very high ratings. Polygons with moderate and high ratings require less separation and can be grouped together if required.

Example B. If the main applications of the vulnerability potential mapping are 1, 3, and 4, the field work should aim to separate all four ratings.

3.3.3 Task 3 – Identification of significant surface karst features and hydrological features

The identification of significant surface karst features at the planning level is important because they provide a general sense of the magnitude of the karst system within a specific area. This information is useful for both assisting forest development planning (e.g., layout of cutblocks or roads) and for directing further inventory work. At this level, the term “significant” for a surface karst feature is somewhat subjective, and is generally a function of size. However, a group of small features (e.g., swallets or springs) could also be significant, as would a small cave entrance that leads into a large cave system. (Evaluating the significance of surface karst features is further discussed in Section 4.3.5 and in Appendix C.) Many large surface karst features, typically greater than 20 m in surface dimensions (length, width, diameter), can be identified in air photos by canopy gaps in the forest cover (e.g., a karst canyon or large sinkhole). Field work carried out during the planning-level inventory should be designed to intersect as many of these significant features as possible.

Another important consideration is to identify potential areas where significant karst features might be present, but are not visible in the air photos. This can be done by using predictive techniques based on an understanding of karst-forming processes. For example, a gully extending up a slope underlain by limestone might lead to a karst spring, or the upper geological boundary of a karst unit would be a likely site for swallets.

Details on measuring and classifying surface karst features are outlined in Section 4.3.5 and Appendix D. A list of on-site map symbols used to indicate types of surface karst features is provided in Figure 4.6.

Streams on karst terrain can be identified, mapped, and classified at the planning level, as illustrated in Figure 4.6. However, the main emphasis should be on mapping the characteristics of larger streams, or ones that display distinctive karst processes (e.g., losing, sinking, or gaining streams). Streams are not directly included in the vulnerability potential rating because of the inherent complexity of integrating linear features with polygons. However, in many cases, there is a direct correlation between the number of streams and surface karst features. For example, a large number of streams flowing onto an upper karst boundary will likely develop a large number of swallets.

3.3.4 Task 4 – Determination of karst catchment and hydrology

One characteristic of karst terrain that differs significantly from non-karst terrain is its hydrological system. Typically, karst hydrological systems can include complex subsurface drainage networks and catchment areas that do not necessarily follow topographic divides, and, in many cases, cross them. Hence, karst hydrological systems can be characterized as highly variable and difficult to predict from surface features. Data from Tasks 1, 2, and 3 can be useful in determining the extent of the karst catchment for a site and the likely subsurface hydrology. In some cases, subsurface hydrological flow paths can be inferred from the surface drainage patterns, site geology, and surface karst features; however, in most cases, the subsurface hydrological flow paths are less clear. At the planning level, it is possible to delineate watershed divides and determine the karst and non-karst components of the topographic catchment. The adjacent non-karst component of the topographic catchment, if upslope from the karst unit, can have a significant influence on the karst hydrology down-slope. Where the karst unit extends across the watershed divide, there exists some possibility for adjoining karst and non-karst catchments (see Section 3.2 and Figure 3.2). A valuable tool for evaluating the extent of karst catchments and subsurface flow paths is dye tracing.

Dye tracing

Dye tracing is a well-accepted methodology for evaluating karst hydrological systems in forested terrain (Stokes and Griffiths 2000). It is undertaken using one or more flourescent dyes that are injected into a recharge site (e.g., sinking stream), and then tracked through sampler sites located at likely discharge locations (e.g., springs). Typical objectives for a planning-level dye tracing investigation might include determining:

- the likely extent of the catchment area;
- the main recharge and discharge areas;
- the location and connectivity of subsurface conduits (or groundwater flow paths); and
- the subsurface flow response/transit times.

Dye tracing conducted at the planning level is not intended to be an exhaustive procedure, but rather to provide a general idea of the karst hydrology, and give an indication as to whether further detailed investigation may, or may not, be required.

Dye tracing projects should be designed and carried out by experienced personnel. Conceptual design should be completed prior to any field work, where clear objectives and favourable locations for dye injection and sampler sites are identified. Appropriate dyes and samplers should be chosen for the site conditions. Various interested agencies (e.g., Federal Department of Fisheries and Oceans, Ministry of Water, Land and Air Protection) should be informed of the location and timing of the dye tracing. Prior to dye placement, water samples should be taken at injection and collection sites for background analysis, particularly if previous dye tracing has been carried out in the area. Water at the injection and collection sites should be tested for temperature, pH, dissolved oxygen, and conductivity. Water flow estimates should be made at both injection and sampler sites. Precipitation data should be obtained from a nearby registered rain gauge if available; if not available, a simple rain gauge should be set up at a suitable location for the duration of the field work.

Retrieval and replacement of dye samplers should be carried out strictly, according to approved procedures. A labelling protocol and chain of custody should be implemented, with all samples being shipped directly to an approved laboratory for analysis. These samples should be prepared and analyzed according to accepted laboratory standards and procedures. Analytical results should be certified by the laboratory. Following completion of the dye tracing and analysis, a map (or layer in a GIS database) should be completed showing dye paths and travel times of groundwater flow, boundaries of the recharge areas, insurgences, and exsurgences. For further explanation and examples of dye tracing techniques, materials, and analytical procedures, refer to Stokes and Griffiths (2000).

The need for dye tracing is highly dependent on site conditions, and relies on the following factors:

1. the anticipated complexity of the groundwater flow paths;
2. the number and size of discrete inflow and outflow sites; and
3. the complexity and size of the karst catchments.

Table 3.7 provides some general guidelines for determining the need for dye tracing. The intent of the table is not to cover all situations, but rather to provide an indication of some of the site conditions where dye tracing could be utilized.

3.3.5 Task 5 – Identification of karst flora and fauna, and associated habitats

The identification and evaluation of unique or unusual karst flora and fauna, and their associated habitats, is a complex and specialized field (e.g., Chapman 1993) with only a few specialists worldwide capable of completing full karst biota inventories either on the surface or subsurface. Nevertheless, a pragmatic approach to identifying karst flora and fauna, and their associated habitats, is recommended for both planning-level inventories and KFAs (see Section 4.3.12). The recommended approach is to focus on likely habitats for karst biota (see Table 3.8), rather than trying to identify any particular fauna or flora species. Some of the key habitats for karst biota occur around karst springs, cave entrances, well-developed epikarst and solutional grike fields, along karst bluffs or canyons, and around large and/or deep sinkholes, swallets, and cave entrances. All of these habitats are where a variety of karst flora and fauna species can exist under relatively shaded and consistent temperature conditions. Any sites where there is a diversity of plant species are also likely to be good habitat for karst fauna.

Identified karst habitats should be carefully described and mapped as part of the planning-level inventory. If karst flora/fauna habitat sites are considered significantly large or unusual, they could be utilized to influence the vulnerability potential rating of a polygon by increasing it by one or possibly two levels (e.g., from low to moderate, or low to high). This would ensure further evaluation of these sites at the KFA level. In cases where habitat sites are small or point features, it is suggested they be highlighted as specific locations for further inventory work, rather than be used to influence the overall polygon vulnerability potential rating.

Table 3.7. **Determining likely dye tracing requirements at the planning level**

Catchment conditions	**Karst type** **Young** or **Merokarst** (Karst development follows existing surface drainage) **Subsurface hydrology** Relatively straight-forward subsurface hydrology anticipated	- - - - - - - - - - - - - - - - - - - → Moderately complex subsurface hydrology anticipated	**Old** or **Holokarst** (Karst with little to no surface runoff or streams) Complex subsurface hydrology anticipated
Karst unit confined to one topographic catchment, with small upslope non-karst component	M	S	D
Karst unit limited in extent, but crosses at least one topographic watershed / major creek drainage, with considerable upslope non-karst component	M	S	D
Karst unit crosses a number of topographic watershed divides, and has adjoining karst and non-karst catchments.	S	D	D

M – Most of the subsurface hydrological links at the site can be determined from the surface drainage patterns and hydrological features. Dye tracing is unlikely to uncover subsurface flow paths different from the ones determined from the surface drainage patterns.
S – Some of the subsurface hydrological links can be inferred from the location of hydrological features. However, there is some element of doubt. Dye tracing is suggested to confirm the postulated subsurface flow paths and the likely extent of the catchment.
D – Determination of the subsurface flow paths from the surface drainage patterns and hydrological features alone could be misleading. Dye tracing is highly recommended to confirm the subsurface flow paths and the likely extent of the catchment areas.

Table 3.8. **Preliminary list of habitats for karst-specific flora and fauna**

Karst habitpat	Mosses	Lichens	Plants	Insects	Mammals	Amphibians/ Fish
Cliff/Bluff	L	L	L	L	U	P
Canyon	L	L	L	L	P	L
Large sinkhole	P	P	L	P	U	U
Swallet	P	P	L	L	P	L
Spring	L	P	L	L	L	L
Large grike	L	L	L	P	U	U
Well-developed epikarst	L	L	L	P	U	U
Cave entrance	L	P	L	L	L	P
Subsurface terrestrial	V	V	V	L	P	P
Subsurface aquatic	V	V	V	L	U	L

L – likely to be encountered
P – possibly encountered
U – unlikely to be encountered
V – very unlikely to be encountered

3.3.6 Task 6 – Identification of geomorphic hazards

The identification of geomorphic hazards that could potentially affect a karst unit is another planning-level inventory task. These hazards can occur on the karst unit itself or upslope of the karst unit, and are the result of natural disturbances or human activities, including those related to mass wasting, soil erosion and sediment transport, windthrow, and burned areas (see Appendix B). At the planning level, the extent of this task is to record the location, type, and extent of the geomorphic hazards, and briefly evaluate their possible consequences. The hazards are highlighted on the final map, and described in the accompanying report so that further evaluation can be carried out during a KFA, if required.

3.4 Suggested Standards for Reports, Map Presentation, and Personnel

A written report covering all tasks completed should accompany the maps compiled for each project. The report should cover project objectives, information used, regional geomorphology, bedrock geology, karst hydrology, office and field methodologies, and a discussion of results, conclusions, and recommendations. The karst mapping report should approximately follow the guidelines in Section 11 of *Guidelines and Standards for Terrain Mapping in British Columbia* (RIC 1996a). The report should also contain information with respect to data reliability, karst polygon coverage, dye tracing conducted, and any limitations (e.g., areas not assessed).

Bedrock mapping symbols, maps, and cross-sections should be completed to standards outlined in Section 3 of *Specifications and Guidelines for Bedrock Mapping in British Columbia* (RIC 1996b). Karst vulnerability potential maps should closely follow the standards of Sections 8 and 9 in *Guidelines and Standards for Terrain Mapping in British Columbia* (RIC 1996a). The karst mapping can be integrated into a GIS using separate layers for topography, streams, karst unit boundaries, bedrock information, surface karst features, karst polygons, karst catchment, and subsurface flow paths. Data utilized for the karst polygons should be provided as a digital database and included on the map legend. Manual compilation of maps and data is acceptable, providing the appropriate standards are achieved.

It is recommended that planning-level inventories be carried out by a professional with experience in bedrock geology, terrain mapping, and karst geomorphological and hydrological processes. In addition, it is suggested that the person accompanying the professional in the field be a technician who is familiar with karst features and cave entrance inspection procedures. The technician would be able to locate and mark any surface karst features encountered, and rove off the main traverse route to examine any areas of interest. In some cases, rapid examination and inspection of cave entrances could be made during the course of the field work. Continual radio communication between the two workers is essential. Any dye tracing would require the input of an experienced karst hydrologist for project design and data analysis.

3.5 Linkages to the KFA and the Reconnaissance-level Inventory

One of the primary goals of the detailed planning-level inventory and vulnerability potential rating scheme is to identify karst polygons that require further karst inventory and vulnerability assessment at the KFA level. The methodology for the planning-level vulnerability potential rating procedure is intentionally conservative, defaulting, in most cases, to the highest rating category of the controlling attribute (see Section 3.3.2). This ensures that any karst polygons of concern are identified and evaluated in more detail at the KFA level. In general, polygons with low vulnerability potential ratings would not normally require a KFA, whereas those polygons with a moderate, high, or very high rating would receive a KFA.

Findings and data from the planning-level inventory should be linked back to the reconnaissance-level inventory to refine karst potential ratings for Criteria #1 and #2, and to add further known cave and karst inventory information (Criterion #3). These data can then be extrapolated to adjacent areas where little or no known karst information is available.

4.0 Karst Field Assessment

4.1 Goals, Objectives, and Approach

This section describes the methodology used for completing a karst field assessment (KFA). These detailed inventories are conducted at the 1:5000 or 1:10 000 map scale to collect data on the karst unit of interest within or adjacent to a localized area of proposed development (usually a cutblock or road). The data collected are used to identify specific karst features and streams that may require special management, to divide the karst unit of interest into areas of similar karst characteristics (i.e., polygons), and to assess the vulnerability of the karst polygons. This information is then used to guide the use of appropriate forest management practices for karst terrain, as recommended in the *Karst Management Handbook for British Columbia* (B.C. Ministry of Forests 2003).

The principal objectives of a KFA are:

- to determine the boundaries and likely three-dimensional nature of the karst unit of interest;
- to locate, identify, and classify key surface karst features;
- to evaluate the significance of specific surface karst features;
- to divide the karst unit of interest into areas (polygons) of similar karst characteristics;
- to assess the level of epikarst sensitivity;
- to assess the level of surface karst sensitivity;
- to evaluate the topographical roughness of the karst surface;
- to identify sinking and losing streams and karst springs, and assess the hydrology of the karst unit of interest;
- to estimate subsurface karst potential, and evaluate and map caves to the level and extent required;
- to identify unique or unusual karst flora/fauna and associated habitats;
- to identify any geomorphic hazards that could potentially affect the karst unit of interest; and
- to assess the vulnerability of the polygons within the karst unit of interest.

A KFA may be initiated under the following circumstances:

- an area proposed for development is underlain by known or suspected carbonate bedrock[12];
- development is proposed on non-carbonate lands located upstream (within the contributing catchment) of known or suspected carbonate units[13];
- reconnaissance-level karst potential maps indicate that the area proposed for development may be underlain by carbonate bedrock;
- a planning-level inventory identifies karst polygons with moderate, high, or very high vulnerability potential ratings in or around an area of proposed development;

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[12] Or other soluble rocks able to undergo karstification (e.g., gypsum).

[13] In this case, the KFA would be carried out on the known or suspected carbonate units located downstream of the proposed development, including any contiguous carbonate units in adjacent or adjoining catchments.

- there is previous knowledge of karst topography in or around an area of proposed development;
- specific karst features have been identified on the ground in or around an area of proposed development; or
- post-harvest activities, such as windthrow salvage, juvenile spacing, pruning, commercial thinning, or fertilizing, are planned on an area known or suspected to be underlain by carbonate bedrock.

Overall, KFAs focus on identifying karst attributes that are relatively stable and reliably mapped.

KFAs are primarily surface karst inventories and use methods of observation that most forest workers are familiar with. However, various levels of subsurface investigation and mapping are required where caves are identified in order to effectively evaluate the three-dimensional aspects of the karst system and provide specific information that may be required for applying effective management strategies at the surface (e.g., the location of caves with thin ceilings).

In most cases, a KFA is likely to be the first karst inventory work completed for an area, other than the reconnaissance-level (1:250 000) karst potential maps. (To date, very few planning-level karst inventories have been completed in British Columbia.) Where planning-level inventory information is limited or unavailable, the scope of the KFA may need to be expanded to encompass some of the relevant planning-level tasks.

4.2 Office Review

There are several stages to successfully completing a KFA, beginning with an office review (see Figure 4.1). The office review is conducted prior to initiating field activities to help establish and define the site-specific objectives and goals of the inventory. All existing data on the area of interest are collected and analyzed. This information helps direct field activities, and avoids possible duplication of work.

A good way to initiate an office review is with a literature search using gazetted geographical or local place names associated with the location of the KFA. This can be done using the Internet, library catalogues, other resource inventories, etc.

Licensees, the Ministry of Forests, and other appropriate agencies (e.g., the Ministry of Water, Land and Air Protection, the Ministry of Sustainable Resource Management) will generally be able to provide most of the background information required for a KFA. Local caving groups may also be able to provide useful information in some cases.

A good source of geological information is the Ministry of Energy and Mines database of mineral occurrences (Minfiles). This database is located at: www.em.gov.bc.ca/mining/geolsurv/Minfile/minfpc.htm. These files commonly describe the bedrock geology of an area (including carbonates), and usually provide maps.

The following tasks should be completed during the office review stage of a KFA:

- Review any data from reconnaissance-level and planning-level karst inventories (if available), including the results of dye tracing and hydrogeological investigations. Review all available KFA reports and maps completed for nearby areas.
- Assemble all available information on the karst unit of interest from air photos, and from topography, bedrock geology, surficial geology, and terrain maps. (If the area has been

previously harvested, historical air photos may be useful for identifying surface karst features.)

- Collect any other existing information on the karst unit's terrain features, soils, topography, ecosystems, and flora/fauna using available mapping and other resource inventories (e.g., terrestrial ecosystem, terrain mapping, fish habitat, forest cover).
- Obtain all available karst/cave information for both the area of interest and adjacent areas.
- Determine any relevant requirements from FPC guidelines, higher level plans, or cave/karst management plans. Review the types of proposed development activities (e.g., road locations, harvesting methods). Obtain any local knowledge on the area or adjacent areas (e.g., windthrow potential).
- Construct or obtain a base map at the required scale (licensees can often provide topographic maps of the area at 1:5000 or 1:10 000 scale). Base maps can be either hard copy or digital (for use within a GIS environment). Base map layers should include contours, bedrock geology, surface streams, forest cover, soils (thickness/type), and proposed development areas.
- Plot any known surface karst features on the base map using appropriate linework and approved symbol conventions (see Figure 4.6). Project the outline of any known cave passage in plan view. Known swallets and karst springs should also be plotted.
- Set the preliminary boundaries for the KFA (see following section), and develop a comprehensive plan for carrying out field activities, in terms of both logistics and appropriate inventory techniques (e.g., types of ground searching methods).

OFFICE REVIEW:

Obtain all previous karst information – reconnaissance-level karst potential maps, planning-level karst inventories, other karst inventory or cave information for the area of interest and/or adjacent areas.
Gather all other available information – air photos; detailed topography, bedrock geology, surficial geology, and terrain maps; data on soils, vegetation/ecosystems, forest cover, and fish habitat.
Construct a base map, either manually or in digital format with a series of layers – include layers for contours, bedrock geology, surface streams, forest cover, soils (thickness/type), and proposed development.
Review any relevant requirements for the area – FPC guidelines, higher level plans, karst/cave management plans, proposed development activities, and local knowledge (e.g., windthrow potential).
Plot all karst data on the base map using standard symbol conventions – include surface karst features, epikarst zones, streams, hydrological features, and the outline of any known cave passages in plan view.
Set preliminary boundaries for the KFA – based on the type of proposed development (e.g., cutblock, road) and the location of the development area in relation to the karst unit.

FIELD ACTIVITIES:

Ground Searching – locate surface karst features and streams.

Surface Mapping – divide karst unit into polygons of similar karst characteristics, and evaluate surface karst attributes (e.g., surface karst feature density, roughness, flora/fauna).
Karst Boundaries – confirm where encountered in the field.
Surface Karst Features – classify; determine significance; field mark, geo-reference, and plot.
Epikarst Sensitivity – epikarst development; soil thickness and texture; rate for epikarst sensitivity.
Surface Karst Sensitivity – surface karst feature density; rate for surface karst sensitivity.
Karst Roughness – rate for karst roughness.
Streams and Hydrology – stream types; assessments and mapping; recipient features; sinking watercourses.
Subsurface Inspection and Mapping – assess caves for significance; survey caves to establish location with respect to the surface.
Subsurface Karst Potential – estimate based on watercourse characteristics, the presence of caves, and the presence of large-scale negative relief features.
Unique or Unusual Karst Flora and Fauna – identify by species or favourable habitat.
Geomorphic Hazards – identify for further evaluation.
Karst Vulnerability Assessment – use four-step procedure to determine vulnerability ratings for karst polygons.

REPORT AND MAP COMPILATION:

KFA Reports:

- follow standard technical report format.
- results section – description of karst features/attributes; vulnerability ratings for karst polygons; description of any geomorphic hazards.
- recommendations section – recommended management strategies and rationales.
- written in technically accurate language for wide audience (management to field staff).

KFA Maps:

- final map data generally in GIS-compatible digital format.
- manual maps may be acceptable in some cases, but generally less usable.

KFA Information Management:

- develop procedures to ensure that sensitive karst inventory data are kept secure.

Figure 4.1. **Methodology for the karst field assessment.**

4.2.1 Determining preliminary boundaries for a KFA

An important part of the office review is to set the preliminary boundaries of the area to be covered by a KFA. This is typically the karst area within a proposed cutblock and/or the karst area potentially affected by an upslope cutblock or road located within a contributing non-karst catchment. In general, KFAs will focus on a small area of karst that occurs within a larger karst unit.

The following examples provide guidance for setting preliminary boundaries for KFAs where information from planning-level inventories is available for the surrounding area. In cases where no planning-level information is available, the size of the search area may need to be increased to reduce the risk of missing important karst features that could be affected by the proposed cutblock or road.

Preliminary KFA boundaries for proposed cutblocks or other development areas

Cutblock Scenario #1 -- The proposed cutblock is located within a karst unit.

Decision Points:

Does the background information collected during the office review provide reliable data on the karst unit boundaries within and adjacent to the proposed cutblock?

If **YES** -- Set the preliminary boundaries of the KFA to include those areas of the proposed cutblock that fall within the karst unit boundaries, plus a minimum 100-m extended area. **(see Figure 4.2 A)** The extended area is a precautionary measure to search for nearby karst features that may be affected by the cutblock. For example, a cave entrance located outside the cutblock boundary may have interior passages that extend back underneath the cutblock. In addition, nearby significant surface karst features or sinking and losing streams may require reserves and/or management areas during future development, which could impinge on the boundaries of the proposed cutblock. Depending on the characteristics of the karst in the area, the shape and width of the extended area may need to be adjusted based on professional judgement.

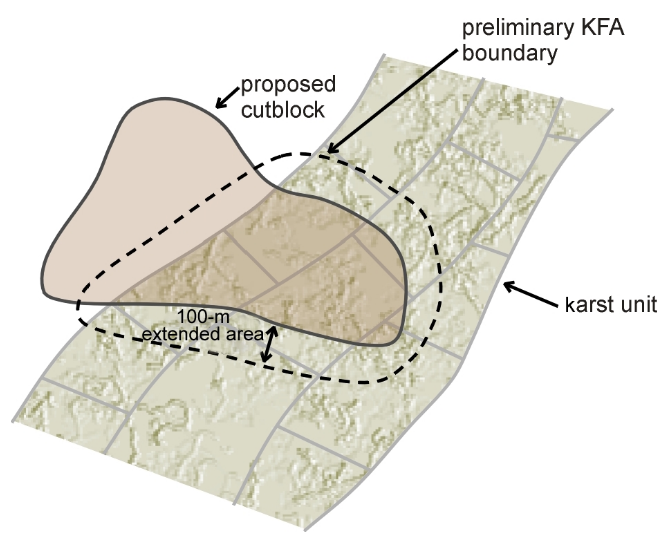


Figure 4.2 A

Figure 4.2.
Scenarios for determining preliminary KFA boundaries (A–I).

If **NO** -- Plan to conduct the KFA on the entire proposed cutblock area plus a minimum 100-m extended area. **(see Figure 4.2 B)**

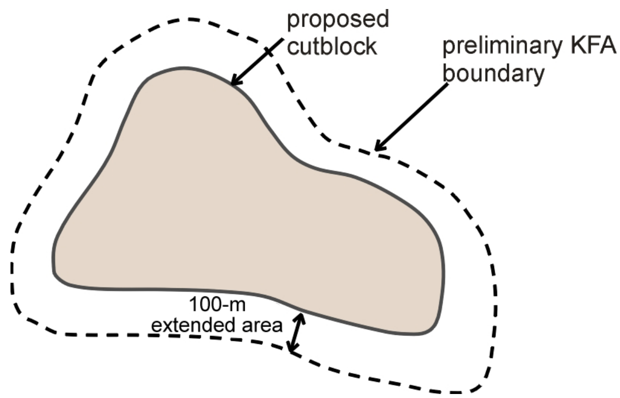


Figure 4.2 B

Are there any streams in the cutblock or the 100-m extended area? (Includes streams on any non-karst portions of the proposed cutblock that flow onto downstream karst.)

If **YES** -- Conduct stream assessments to identify and locate stream characteristics (e.g., sinking, losing, gaining segments). **(see Figure 4.2 C)** Stream assessment distances are based on channel width, which is an indicator of transport potential, and are the minimum distances required to search for recipient karst features where sediment and other debris could be transported into subsurface karst environments. Specific stream assessment distances are addressed in Section 4.3.9. When recipient karst features are identified during a stream assessment, they need to be evaluated for their significance.

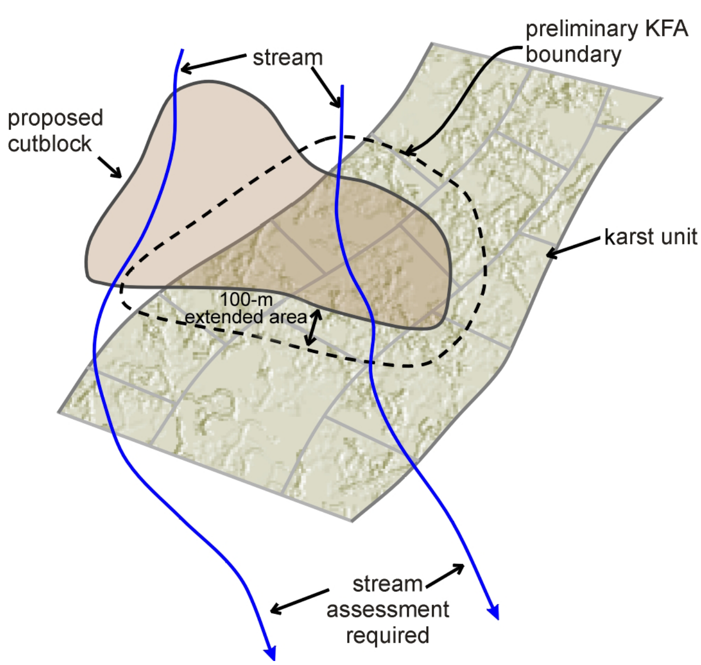


Figure 4.2 C

If **NO** – No stream assessments are required.

Cutblock Scenario #2 -- The proposed cutblock is located more than 100 m upslope of a known karst unit on the non-karst portion of the karst catchment. **(see Figure 4.2 D)**

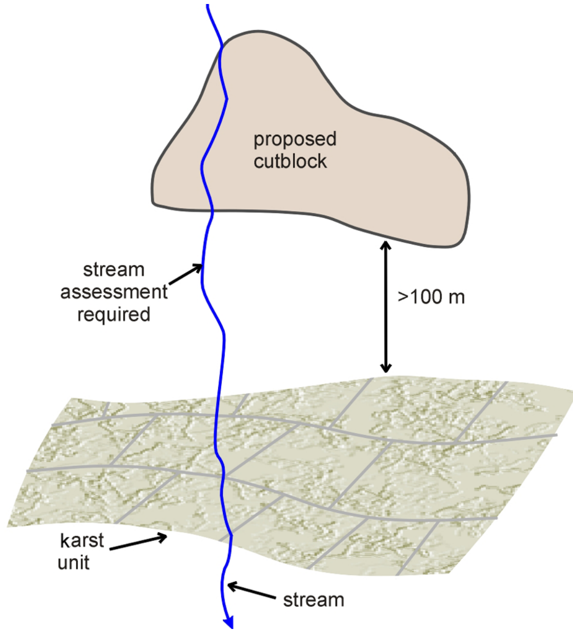


Figure 4.2 D

Decision Points:

If there are no streams in the proposed cutblock or the minimum 100-m extended area, there is no need for a KFA on the downslope karst unit.

If there are streams in the proposed cutblock or the minimum 100-m extended area, assess streams for the recommended distances as per Section 4.3.9, and assess any recipient karst features for significance.

Cutblock Scenario #3 -- The proposed cutblock is located on upslope non-karst terrain within 100 m of a known karst unit. **(see Figure 4.2 E)**

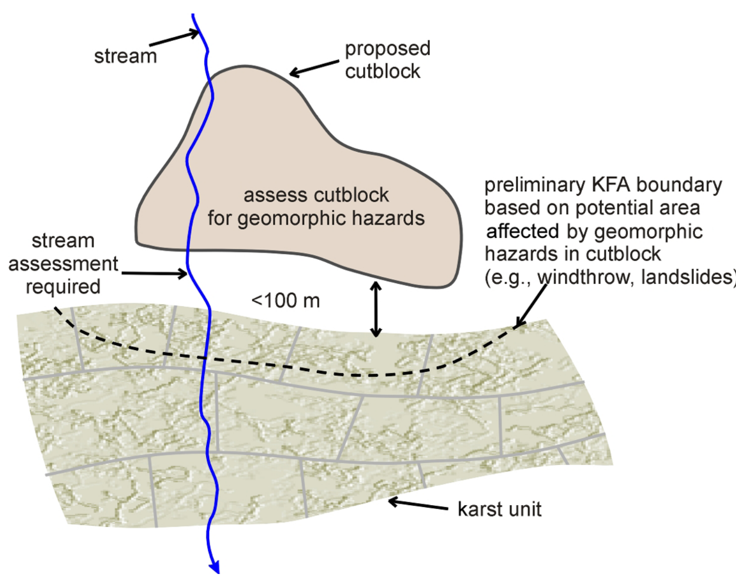


Figure 4.2 E

Identify/confirm the upper boundary of the karst unit.

Assess any geomorphic hazards in the proposed cutblock that could potentially affect the downslope karst unit (e.g., windthrow, landslides).

Decision Points:

If potential geomorphic hazards are identified, conduct a KFA on those portions of the downslope karst unit that could be affected.

If there are no potential geomorphic hazards, there is no need for a KFA on the downslope karst unit.

If there are streams in the proposed cutblock or the minimum 100-m extended area, assess streams for the recommended distances as per Section 4.3.9, and assess any recipient karst features for significance.

Cutblock Scenario #4 -- The proposed cutblock is located on downslope non-karst terrain within 100 m of a known karst unit. **(see Figure 4.2 F)**

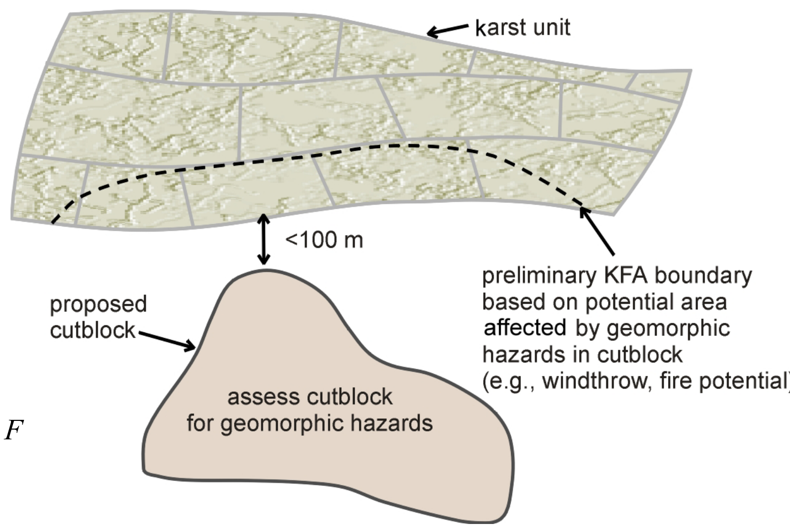


Figure 4.2 F

Identify/confirm the lower boundary of the karst unit.

Assess any geomorphic hazards in the proposed cutblock that could potentially affect the upslope karst unit (e.g., windthrow, fire potential).

Decision Points:

If there are potential geomorphic hazards, conduct a KFA on those portions of the upslope karst unit that could be affected.

If there are no potential geomorphic hazards, there is no need for a KFA on the upslope karst unit.

There is no requirement for stream assessments with this scenario.

Preliminary KFA boundaries for proposed roads outside of proposed cutblocks or other development areas

Road Scenario #1 -- A proposed access road crosses a karst unit outside of a proposed cutblock. **(see Figure 4.2 G)**

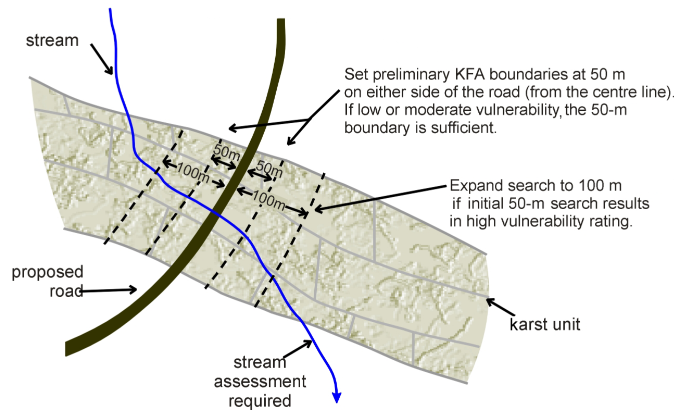


Figure 4.2 G

Conduct a KFA for a minimum 50 m on either side of the road centre line.

Decision Points:

If the resulting karst vulnerability rating is low or moderate, a 50-m KFA boundary is sufficient.

If the vulnerability rating is high, extend the search at least another 50 m on both sides of the road to reduce the risk of the occurrence of a shallow and/or significant cave extending underneath the road.

If the vulnerability rating is very high, the location of the road will have to be moved, and the extent of the KFA will need to be expanded in order to determine an appropriate site for the road.

Does the proposed road cross any streams?

If **YES** -- Assess streams for the recommended distances as per Section 4.3.9, and assess any recipient karst features for significance.

If **NO** -- No stream assessments are required.

Road Scenario #2 -- A proposed access road is located within 100 m upslope of a known karst unit. **(see Figure 4.2 H)**

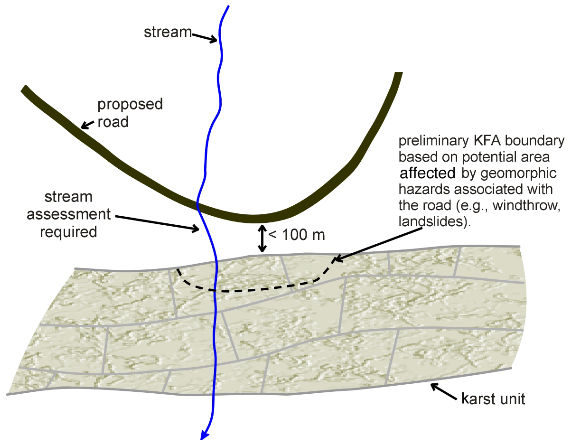


Figure 4.2 H

Identify/confirm the upper boundary of the karst unit.

Conduct a KFA on that portion of the karst unit that could potentially be affected by geomorphic hazards (e.g., windthrow, landslides) or road construction, maintenance, use, etc. (e.g., fuel spills).

Decision Point:

If the proposed road crosses any streams, assess streams for the recommended distances as per Section 4.3.9, and assess any recipient karst features for significance.

Road Scenario #3 -- The proposed access road is located within 100 m downslope of a known karst unit. **(see Figure 4.2 I)**

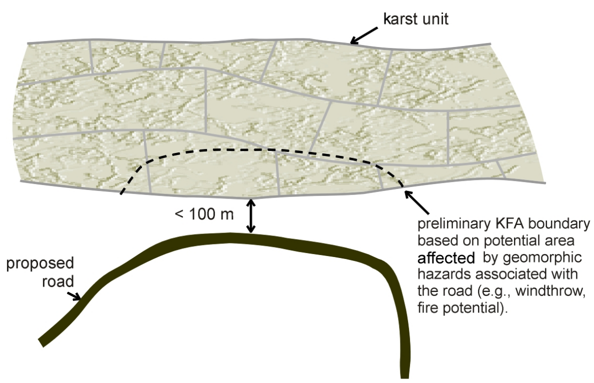


Figure 4.2 I

Identify/confirm the lower boundary of the karst unit

Conduct a KFA on that portion of the karst unit that could potentially be affected by geomorphic hazards (e.g., windthrow, fire potential).

There is no requirement for stream assessments with this scenario.

4.3 Field Activities

The field portion of a KFA requires collecting karst inventory data on the surface and, to a lesser extent, from the subsurface (see Figure 4.3). Major field activities include:

- ground searching;
- surface mapping;
- stream assessments;
- subsurface investigation and mapping; and
- geomorphic hazard identification.

Field activities are applied with varying degrees of emphasis, with most of the field time generally directed towards ground searching and surface mapping. Some overlap or concurrency is common between various field activities (e.g., ground searching and surface mapping).

Prior to initiating detailed field work, an optional preliminary field visit to the karst unit of interest may prove beneficial, particularly if no planning-level inventory has been completed, or if little or no previous knowledge of the area is available. Some of the broader-based planning-level field tasks (e.g., Tasks 1, 3, and 4) can be adopted for this purpose to obtain a general sense of the karst in the area of interest and adjacent areas.

4.3.1 KFAs and safety

Karst landscapes can be hazardous areas to work on due to the irregular terrain and wide variety of surface openings. Caution should be exercised when conducting KFAs on these areas. The following safety precautions are recommended:

- Avoid working alone on karst terrain, or, at a minimum, carry radios and institute a worker-check system as per WCB regulations.
- Consider holding risk assessment sessions prior to initiating KFA activities to discuss site-specific safety concerns associated with the work area.
- All surface karst features that pose a potential safety hazard should be clearly marked with appropriate flagging.
- Hazardous surface karst features, such as vertical shafts, grikes, and steep-sided sinkholes, can be hidden by forest litter, windthrown trees, root masses, or logging slash. Watch footing carefully and wear appropriate head protection and footwear.
- Fallen trees in hummocky karst terrain can be unstable and susceptible to sudden movement when disturbed. Be cautious stepping over or walking on logs.
- When conducting stream assessments, use caution to avoid stepping in active sink points (areas where the stream or a portion of it disappears underground).
- When travelling on roads through well-developed karst terrain, be aware that roads can be susceptible to subsidence or sudden collapse. Pay extra attention to road conditions.
- Personnel conducting subsurface inspections should be aware of the guidelines specified under Part 9, Confined Spaces, of the Occupational Health and Safety Regulation, as well as other applicable WCB regulations.
- In the event of cave rescues or other emergencies, call the local RCMP detachment or the PEP Emergency Coordination Centre at 1-800-663-3456.

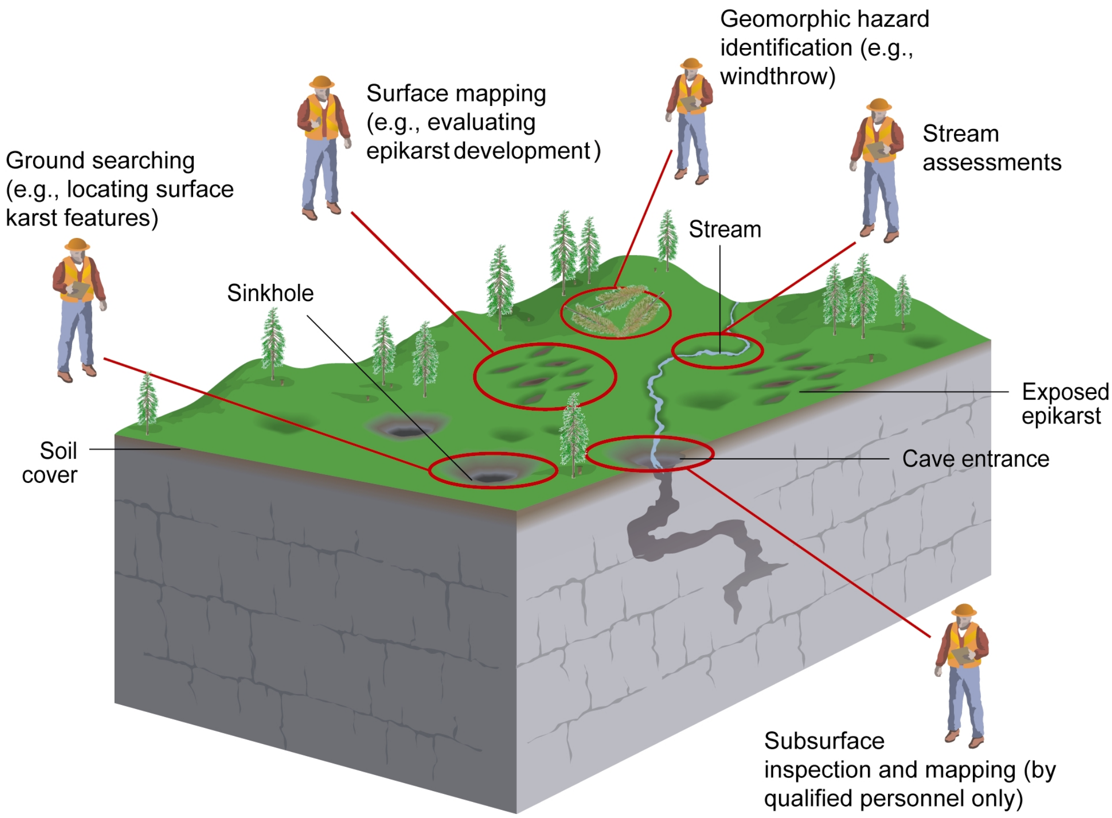


Figure 4.3. **Field activities for collecting key karst attribute data.**

4.3.2 Ground searching

The primary purpose of ground searching is to locate specific surface karst features, sinking and losing streams, and karst springs.

Four common ground searching techniques are typically used for KFAs:

- reconnaissance or linear transect search;
- judgemental search;
- multiple transect or grid search; and
- total (saturation) search.

See Figure 4.4 for a graphic depiction of the four ground searching techniques.

The **reconnaissance** or **linear transect search** is commonly used as an initial field orientation, and consists of a traverse line or bearing with minor deviations across the inventory area. This type of search is also suitable for road locations or streams that cross karst, where a linear route is followed.

The **judgemental search** is based on the recognition that karst development generally does not occur in a random fashion, and that it is possible to identify associations between karst development and terrain variables (e.g., the correlation between sinkholes and lower slope gradients). By using this approach, an experienced field worker can predict where features are more likely to be found, and traverse routes can be designed and optimized accordingly. This can be an effective method for concentrating field work on critical areas and avoiding detailed work in areas of less concern.

The **multiple transect** or **grid search** is useful where discrete karst features (e.g., cave entrances) are less predictable and spread more randomly throughout an area. The grid layout, spacing, and orientation of search lines are based on practical considerations (e.g., understorey thickness, terrain steepness) and an assessment of where the most information might be obtained. These grids can be constructed by a single compass person along a centre line, with lateral rovers identifying/locating/mapping surface karst features and relevant attribute data.

The **total (saturation) search** is used for critical areas within cutblocks or along roads (e.g., highly developed karst with many concentrated features). This method uses high-intensity search patterns (e.g., grids, concentric circles, or lateral loops), with the intention of covering all ground within the field of view (e.g., 5- to 20-m spacing, depending on vegetation cover).

These four ground searching techniques can be combined, stratified, or modified to suit local field conditions. Selecting the most appropriate ground searching technique for a particular area is based on the type of karst terrain encountered, the experience of the field worker, and the proposed development activities. For example, a judgemental search may be more appropriate for a hillslope, where karst features tend to be associated with slope position (e.g., springs on lower slopes). Flatter ground may be better suited to a multiple transect or grid search since the location of karst features tends to be less predictable in these types of areas.

Advantages and disadvantages of the four ground searching techniques are more fully described in *Searching for Cave Entrances in Old-growth Forests: An Overview of Ground-based Methods Employed in North and Central Vancouver Island, British Columbia* (Griffiths 1997). (See Appendix E.)

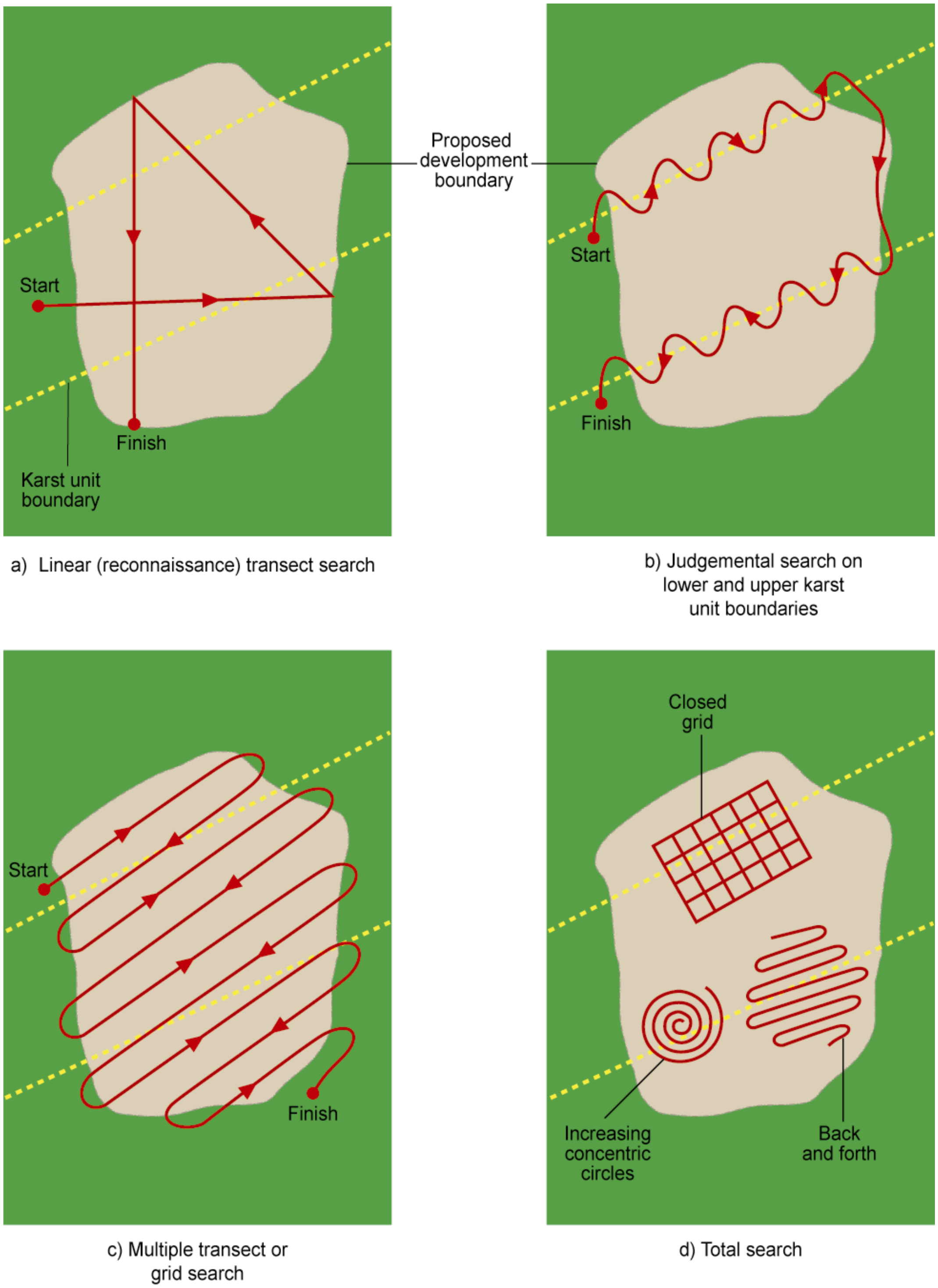


Figure 4.4. Ground searching techniques.

4.3.3 Surface mapping

Surface mapping is used to assess the surface karst attributes within the KFA area. There are two major tasks associated with surface mapping:

- evaluating and mapping epikarst development, soil thickness and texture, surface karst feature density, karst roughness, and unique or unusual karst flora and fauna; and
- dividing the KFA area into polygons representing areas of similar karst characteristics.

Surface mapping is often carried out concurrently with ground searching. As a KFA area is traversed, surface karst attributes are evaluated as they are encountered, and observations are recorded in field notes. Surface karst attribute data are extrapolated to areas not covered by the traverse route.

Photographs can serve as a useful record of representative sites and attributes. The locations of observation stops, photo points, and traverse routes can be plotted on the base map.

Karst polygons are used to define areas of relatively uniform karst characteristics that will subsequently be rated for karst vulnerability. The area within karst polygons can be delineated using two physically stable, easily recognized surface karst attributes—the level of epikarst development and the density of surface karst features.

These two surface karst attributes correlate well with other surface karst attributes. For example, high levels of epikarst development and high densities of surface karst features are generally associated with thinner soils, higher karst roughness, and the presence of unique or unusual karst flora/fauna. Because of this correlation, it is usually not necessary to consider more than epikarst development and surface feature density for delineating areas of similar surface karst characteristics. This makes the process of establishing karst polygons much simpler and efficient; however, a degree of interpretation and professional judgement may be required to characterize zonal patterns.

The average karst polygon is typically between 10 and 20 hectares in area (e.g., a 40-ha area would likely be divided into two or three karst polygons).

Surface mapping is not applied as a rigorous sampling procedure. The intensity of surface mapping can be adjusted according to site conditions and individual objectives for the KFA. The level of effort will vary according to the type of karst terrain encountered, the experience of the field worker, and proposed development activities (e.g., mapping may be intensified in the vicinity of proposed roads and landings). The overall level of reliability in the data collected can generally be expressed in number of person-days and estimated coverage as a percentage of the KFA area.

4.3.4 Recognizing karst boundaries in the field

Recognizing karst boundaries when they are encountered in the field is an important part of a KFA, as it confirms the geological limits of the karst unit of interest.

Where carbonate bedrock is exposed at the surface, the limit of the bedrock can be used as the karst unit boundary. Karstified carbonate outcrops can be recognized by their typically rounded, light-coloured or grey surfaces, which usually display distinctive solutional characteristics.

Scratching bedrock exposures (e.g., at outcrops, canyons, road cuts) with a steel blade is a simple way to identify carbonate bedrock. Limestone is a relatively soft rock that is easily scratched. Dolomite and marble are somewhat harder than limestone and more difficult to scratch.

Another test for confirming the presence of carbonate bedrock is to carefully place a few drops of dilute (10% molar) solution hydrochloric acid (HCl) on the bedrock (avoiding contact with skin or eyes). The acid readily effervesces (bubbles) with limestone and marble, and, to a lesser extent, with dolomite.

Where carbonate bedrock is not exposed at the surface, terrain characteristics and features resulting from karst processes are used to determine karst unit boundaries (e.g., lack of surface drainage, sinkholes).

Karst unit boundaries are mapped where they are encountered on the ground. Those areas between confirmed boundaries are inferred based on trends of established boundaries, a basic understanding of geological processes and concepts, and the experience of the field worker (see Figure 4.5).

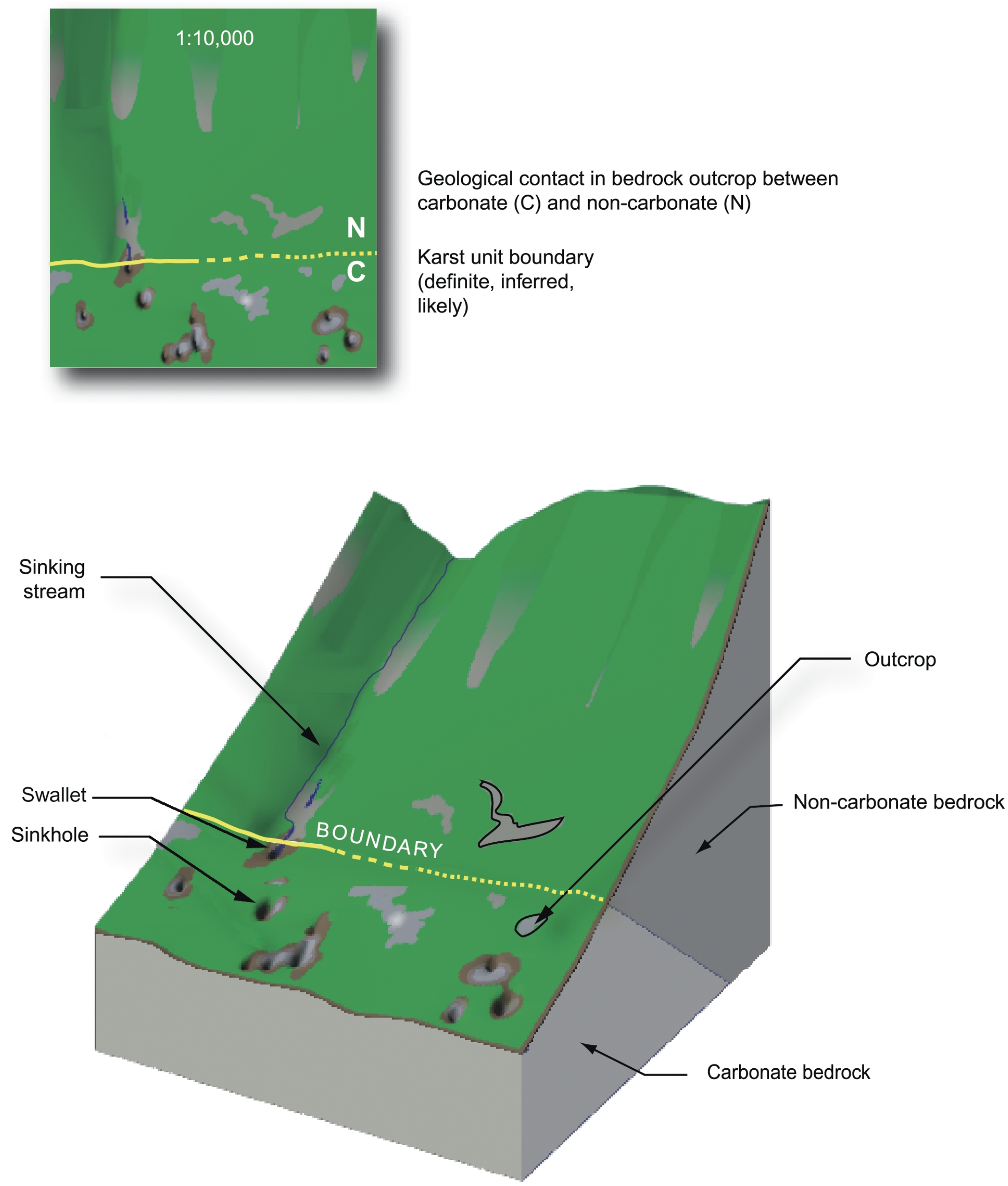


Figure 4.5. **Karst boundary delineation.**

4.3.5 Surface karst features

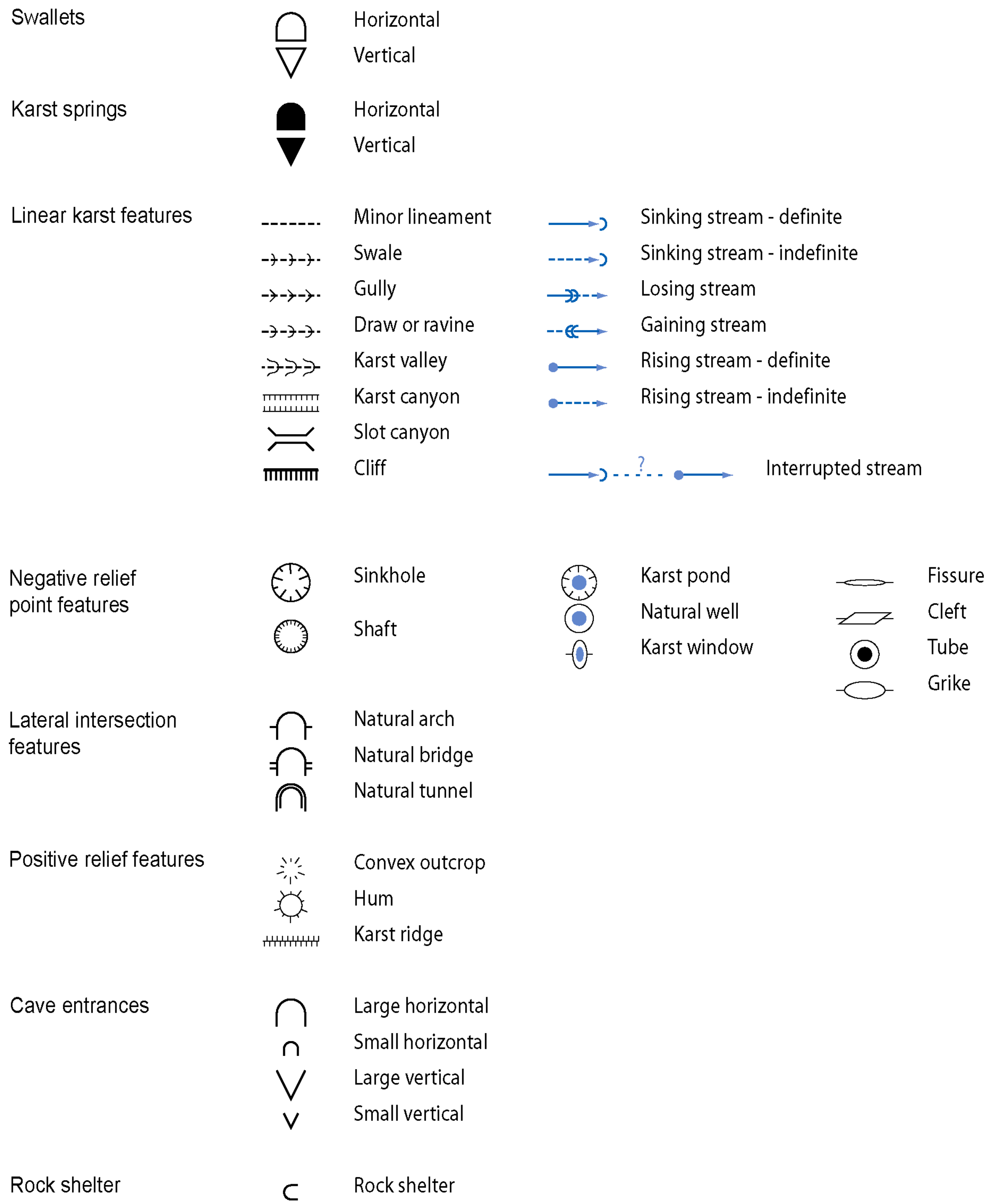
Surface karst features are those features that can be viewed from the ground up to the threshold of daylight within the feature. (Subsurface karst features are those that are beyond the threshold of daylight.) Examples of specific surface karst features include karst springs, sinkholes, cave entrances, and dry valleys.

Surface karst features are found primarily through ground searching, although some are also encountered during surface mapping and other field activities. Only “notable” surface karst features are individually classified, evaluated for significance, field marked, geo-referenced, and plotted on the map. Notable surface karst features are those that are easily recognized, and where the potential for feature-specific management is anticipated. Minor features that do not fall into this category are not individually assessed.

Note: Negative point relief features that have a diameter >2.0 m and < 20 m are used to estimate “surface karst feature density” (see Section 4.3.7).

Classifying surface karst features

Procedures for classifying surface karst features are provided in Appendix D. An example field card for recording surface karst feature data is provided in Appendix F (KFA Field Card #1). Appropriate mapping symbols for surface karst features are provided in Figure 4.6.



Mapping symbols adapted from the International Union of Speleology where available.

Figure 4.6. **Surface karst feature classification scheme and mapping symbols.**

Determining the significance of surface karst features

The decision to assess the significance of a surface karst feature is primarily based on the judgement/experience of the field worker. Generally, only notable surface karst features are evaluated for significance.

Surface karst features that are not obviously sensitive or technically difficult (e.g., not requiring ropes or special climbing equipment) can be assessed for significance by KFA field workers. Sensitive or technically difficult surface karst features should be examined only by experienced personnel.

Surface openings that could be potential cave entrances need to be examined to determine if they are part of a cave. If a surface opening leads to a cave, a subsurface inspection is required (see Section 4.3.10).

Determining the significance of surface karst features is a qualitative evaluation of the following criteria, many of which are interrelated:

- dimensional characteristics
- connectivity
- hydrology
- geological value
- biological value
- scientific and educational values
- archaeological, cultural, and historical values
- recreational and commercial values
- rarity and abundance
- visual quality

The procedure for determining the significance of surface karst features is described in detail in Appendix C. An example field card for evaluating the significance of surface karst features is provided in Appendix F (KFA Field Card #2).

Accurately assessing surface karst features for significance will become progressively easier as the experience of the field worker increases.

Field marking, geo-referencing, and plotting surface karst features

Notable surface karst features are marked in the field with appropriately coloured flagging. Compass and chain measurements are taken from the feature to a nearby reference point (e.g., road station or falling corner). Where site conditions allow, handheld GPS devices can be used to geo-reference features. Accuracy to the nearest 10–15 m is acceptable for most surface karst features. Surface karst features are plotted on the map using appropriate mapping symbols, mapping elements, and a unique identifier (e.g., reference number).

4.3.6 Epikarst sensitivity

Epikarst is a critical component of the karst ecosystem. It includes the sensitive vegetation/soil boundary of the karst system, which, if sufficiently disturbed, can lead to site degradation due to the loss of soil into vertical openings. Epikarst also allows for diffuse water infiltration into the subsurface drainage system, facilitating the potential transfer of sediment and fine organic matter into underground environments.

A number of steps are required to determine epikarst sensitivity.[14] The first step is to estimate the level of epikarst development, the second is to determine the depth and texture of soil cover, and the third is to combine these two variables to determine an epikarst sensitivity rating.

Epikarst development

Epikarst development is evaluated by determining the average depth and frequency of solutional openings [15] within specified size limits. Examples of solutional openings include karst joints, karst fissures, small grikes, solution tubes, and small pits or shafts (see Appendix D).

To be counted as epikarst solutional openings, features should have a minimum surface dimension (length, width, or diameter of a plane formed by the surface opening) of 10 cm and a maximum surface dimension of 1.0 m. The depth of the solutional opening must be at least twice the minimum surface dimension. For example, if the minimum surface dimension is 10 cm, the depth must be greater than 20 cm, or the opening would not be counted.

Surface karst features that are solutional openings with a minimum surface dimension larger than 1.0 m are not included in the evaluation of epikarst development (see Figure 4.7).

Epikarst development is most easily estimated from exposed epikarst surfaces with little or no soil cover as they are encountered during ground searching and surface mapping.

To aid in determining an epikarst development rating, a visual chart has been developed based on the depth and frequency of epikarst solutional openings within a specified area (see Figure 4.8). To use this chart in the field, imagine a 0.01-ha or 100-m^2 circular area within your field of view, and use the chart as a guide to estimate an epikarst development rating.

The depth of epikarst solutional openings are estimated from the lowest point below the surface, which might be the bedrock bottom of the opening or the top of a layer of infilling material, vertically to intersect the plane formed by the surface opening.

The average depth of epikarst solutional openings is estimated as one of four categories: 20–50 cm, 51–100 cm, 101–200 cm, or >200 cm, while the frequency of openings is estimated as <5, 5–10, 11–20, or >20 per 0.01-ha plot. These values are then combined using the visual chart to arrive at a rating for epikarst development: slight, moderate, high, or very high.

Estimates for epikarst development are recorded at stops, and between stops along the traverse route. Epikarst development ratings are interpolated and/or extrapolated (within reasonable limits) to the ground not covered away from stops and routes.

Calibration plots can be used to verify visual estimates of epikarst development and help train the eye of KFA field crews. As field personnel become more experienced with using the visual chart, it should be possible to significantly reduce the number of calibration plots required, or eliminate them altogether.

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[14] "Epikarst sensitivity" is defined as the susceptibility of epikarst and its overlying soil material to disturbance or change, and is a function of the level of openness or connectivity to the subsurface.

[15] A "solutional opening" is defined as one that has slightly rounded edges, has vertical to sub-vertical bedrock walls, and is the result of bedrock dissolution due to karst-forming processes.

Calibration plots for counting and measuring epikarst solutional openings consist of circular plots with a diameter of approximately 11.3 m, encompassing 100 m^2 or 0.01 ha. (see Figure 4.9). The plot centre is marked in the field and geo-referenced to a known position. The plot boundary can be flagged at cardinal points (N, S, E, and W).

Surface karst features that do not meet the criteria for epikarst solutional openings should not make up more than 20% (i.e., 20 m^2) of the calibration plot area, either individually or collectively.

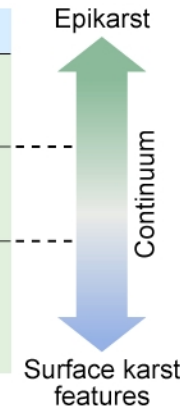
During an evaluation of epikarst development in a calibration plot, it is possible to encounter nested epikarst openings of various sizes (i.e., one or more recognizable openings contained by another). In such a case, only the outer opening is counted. If two or more epikarst openings of roughly equal size coalesce, only the one combined opening is measured. If interior bedrock separations between two coalescing openings are more than half of the height of the larger opening, then the openings are measured separately.

Manual measurements of the depth of epikarst solutional openings in a calibration plot can be conducted using a soil probe (see Soil thickness and texture section, p. 51) or measuring tape.

The average depth and frequency of epikarst solutional openings for a calibration plot are recorded in the same range categories as the visual chart.

The procedure for determining epikarst development requires an integration of visual estimates using the visual chart, supported by calibration plots where required, to arrive at an overall epikarst development rating for the ground observed.

	Diameter	Depth	Length/width
To qualify for epikarst vertical openings	>10 cm <100 cm	>20 cm	<100 cm
To qualify for surface karst features	>100 cm	>200 cm	>100 cm
To qualify for density calculation for surface karst features	>200 cm	>200 cm	>200 cm



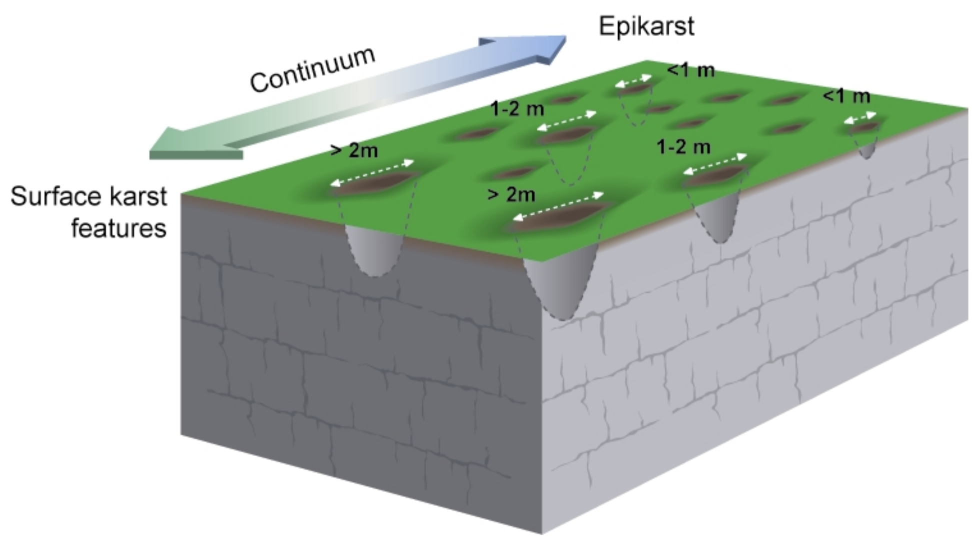


Figure 4.7. Classification of vertical solutional openings and the continuum between epikarst features and surface karst features.

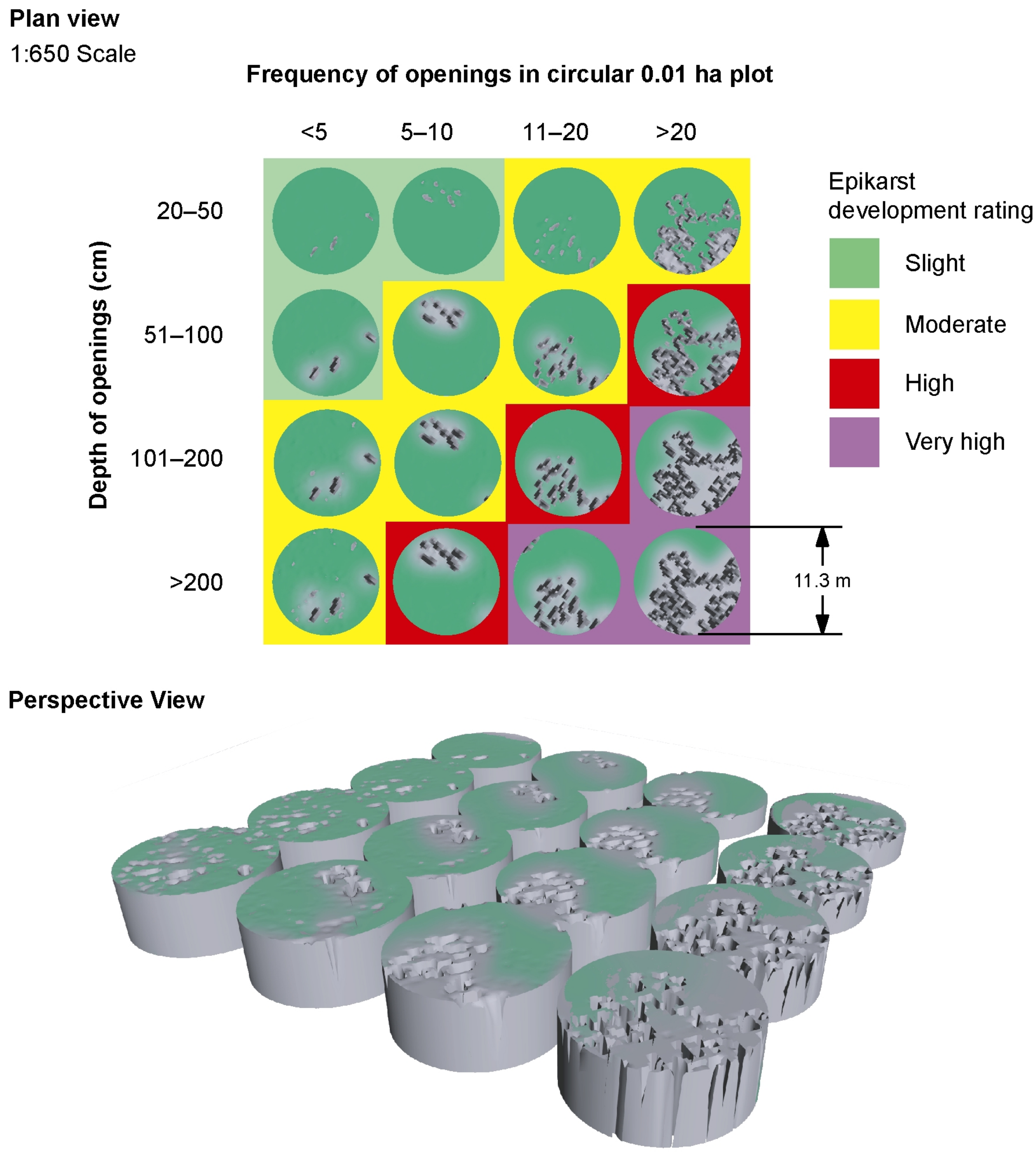


Figure 4.8. **Visual chart for determining epikarst development rating.**

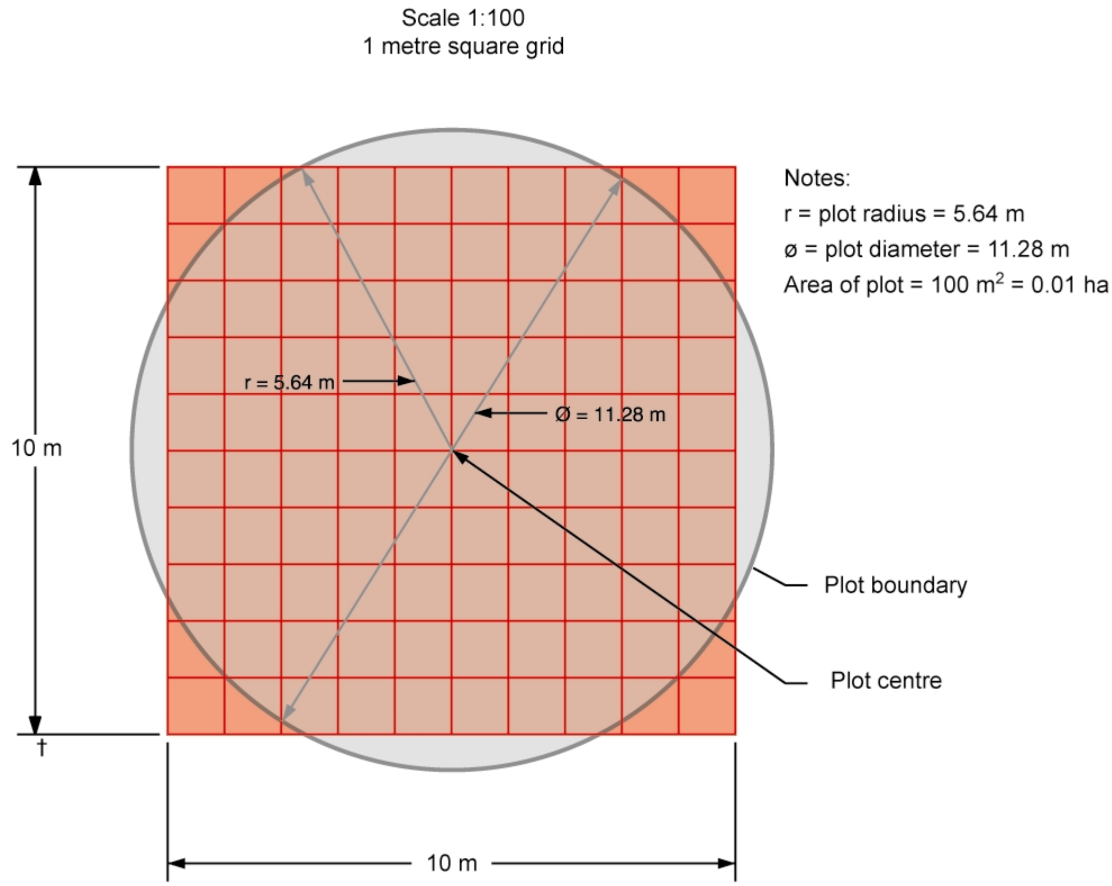


Figure 4.9. **Calibration plot for determining epikarst development.**

Soil thickness and texture

Soil thickness and texture can be estimated using one or more of the following:

- natural exposures (e.g., windthrow);
- small hand pits; or
- steel probes.

Soil thickness in karst terrain can be highly variable at the site level, with thinner soils on partially exposed solutional ridges (i.e., hums), to thicker soil deposits in the intervening low areas (i.e., hollows). When estimating soil thickness, the forest litter or duff layer is considered part of the overlying soil material. (In many cases, forest litter or duff may be the only material overlying epikarst.)

Estimates for soil thickness are recorded at stops, and between stops along the traverse route. Soil thickness estimates are interpolated and/or extrapolated (within reasonable limits) to the ground not covered away from stops and routes.

Manual measurements of soil thickness can be made using a calibrated, metre-long steel probe. The probe is made from heavy gauge (5-mm diameter) steel rod with a right angle bend at the top. Markings at 0.1-m intervals can be indicated on the probe using a black indelible marker.

Average soil thickness for a karst polygon is a weighted average of depth estimates obtained from both hums and hollows. There are six possible soil thickness categories: bedrock, <20 cm, 20–50 cm, 51–100 cm, 101–200 cm, and >200 m.

Procedures for identifying soil textures should follow those outlined in the *Terrain Classification System for British Columbia.* The identification of fine-textured and potentially erodible materials over well-developed epikarst is important, as it is relatively easy to disturb this type of material during surface activities (e.g., cable yarding). For the purpose of this procedure, fine-textured soils of concern are typically those comprised of predominantly silt and sand fines with <20% coarse fragments. If fine-textured soils are present, they can be used as a modifying factor to increase the epikarst sensitivity rating of a karst polygon.

Determining epikarst sensitivity

Epikarst sensitivity combines the two main variables of epikarst development and soil thickness, along with a modifying factor for fine-textured, erodible soils, if present. Table 4.1 uses the epikarst development rating versus an average soil thickness to come up with four ratings for epikarst sensitivity: low, moderate, high, and very high. If a fine-textured, erodible soil is present, the rating for epikarst sensitivity is increased by one category (see Section 4.3.14, Figure 4.14).

Table 4.1. **Rating table for epikarst sensitivity**

Epikarst development rating	Average soil depth (cm)					
	>200	101–200	51–100	20–50	<20	Bedrock
Slight	Low	Low	Low	Low	Low	Moderate
Moderate	Low	Low	Low	Moderate	Moderate	Moderate
High	Low	Low	Moderate	Moderate	High	High
Very High	Low	Low	Moderate	High	Very High	Very High

4.3.7 Surface karst sensitivity

Estimating surface karst feature density

Surface karst feature density is the estimated number of specified surface karst features per hectare. For the purpose of determining surface karst feature density, a countable surface karst feature must be a negative point relief feature (e.g., sinkhole) with a surface dimension (length, width, or diameter of a plane formed by the surface opening) greater than 2 m, but less than 20 m, and a depth greater than 2 m[16] (see Figure 4.7).

Note: The negative point relief features counted in this procedure are generally a subset of all surface karst features encountered in the KFA area (see Section 4.3.5).

[16] Features with surface dimensions within the 1- to 2-m range represent the continuum that exists between countable epikarst openings (<1 m) and what are considered surface karst features for this procedure (>2 m). These kinds of features can be mapped and evaluated individually, or as a group of small features, but are not used in the determination of either epikarst development or surface karst feature density (see Figure 4.7).

The estimated density of surface karst features is recorded in five possible range categories:

- 0 skf/ha;
- 1–5 skf/ha;
- 6–10 skf/ha;
- 11–20 skf/ha; and
- >20 skf/ha.

The density of surface karst features can be estimated directly in the field using a visual chart and/or calibration plots, or as an office exercise after the features have been plotted on the map.

To use the visual chart, imagine a 1.0-ha circular area within your field of view and use the chart as a guide to estimate the density of surface karst features (see Figure 4.10).

Estimates for surface karst feature density are recorded at stops, and between stops along the traverse route. Surface karst feature density ratings are interpolated and/or extrapolated (within reasonable limits) to the ground not covered away from stops and routes.

A calibration plot, similar to that described for epikarst development, can be used to verify visual estimates of surface karst feature density. The calibration plots would have a diameter of approximately 112.8 m and encompass 1.0 ha (see Figure 4.11). The surface karst features within the plot are counted and recorded in the appropriate range category.

Calibration plots are used primarily to confirm visual estimates and train the eye of field workers to recognize the various surface karst feature density ranges. As field personnel gain experience with the visual chart, it should be possible to significantly reduce the number of calibration plots, or eliminate them altogether.

To estimate surface karst feature density after the features have been plotted on the map, use an overlay of a 1.0-ha circle that matches the scale of your map, and count the number of surface karst features within the circle.

Determining surface karst sensitivity

Table 4.2 combines surface karst feature density ratings with epikarst sensitivity ratings (see Section 4.3.6) to determine an overall rating for surface karst sensitivity (low, moderate, high, or very high), which is one of the major factors used in the vulnerability assessment procedure (see Section 4.3.14, Figure 4.14).

Table 4.2. **Rating table for surface karst sensitivity**

Epikarst sensitivity rating	**Surface karst feature density (per ha)**				
	0	**1–5**	**6–10**	**11–20**	**>20**
Low	Low	Low	Moderate	High	High
Moderate	Low	Moderate	Moderate	High	High
High	Moderate	Moderate	High	High	Very High
Very High	Moderate	High	High	Very High	Very High

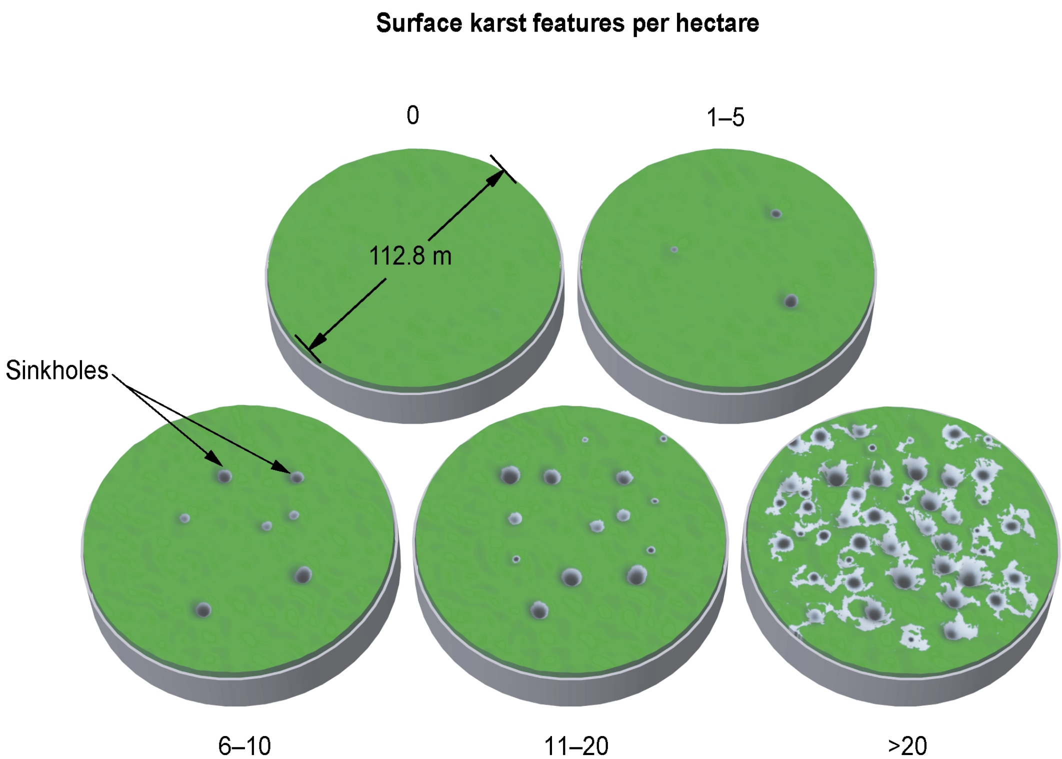


Figure 4.10. **Visual chart for determining the density of surface karst features.**

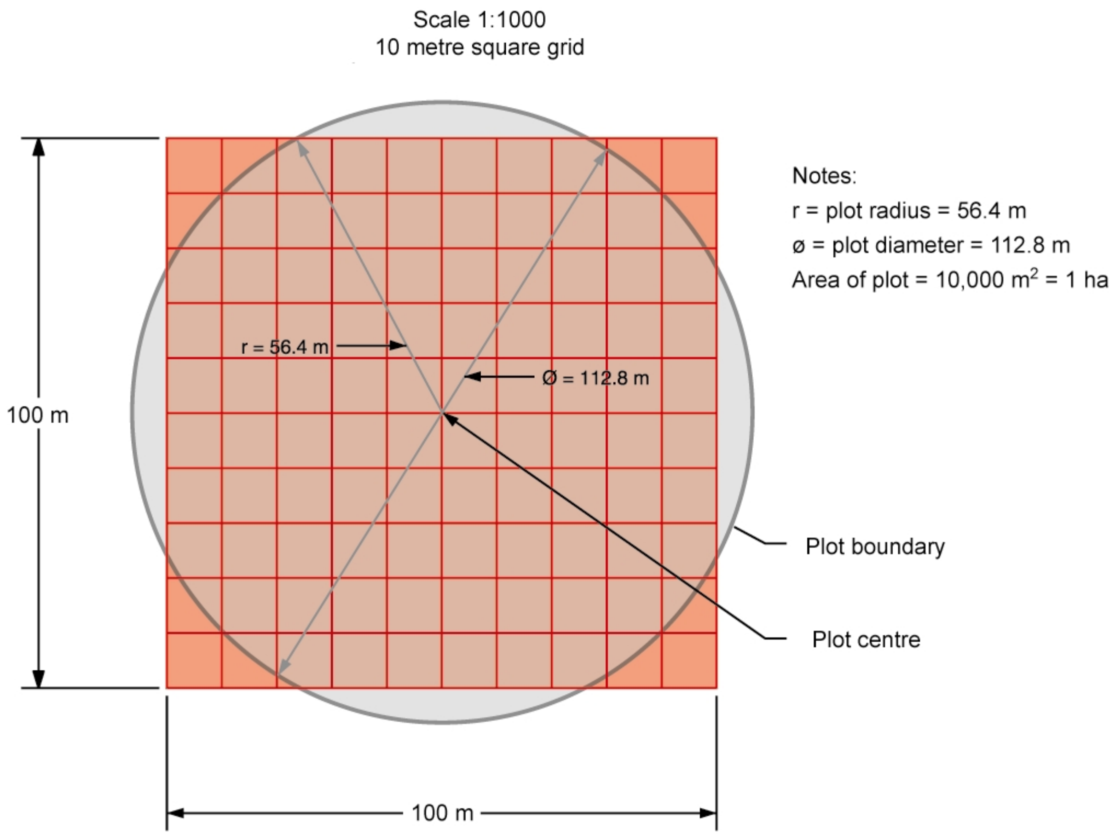


Figure 4.11. **Calibration plot for determining surface karst feature density.**

4.3.8 Karst roughness

Karst roughness describes the inherent characteristics of a karst surface and the overlying soil cover. It is an evaluation of the unevenness or irregularity of the overall karst surface, which can be an indicator of the level of karst development, including subsurface karst potential. A high degree of irregularity in the overall karst surface is a good indicator that the underlying karst is well developed.

Karst roughness considers the proportion of positive relief features to negative relief features (i.e., hums to hollows) and their relative distribution over a particular area. Estimates of karst roughness are particularly useful in areas where there is no exposed epikarst to evaluate.

Ratings for karst roughness are determined using a visual guide (see Figure 4.12). To use the visual guide, imagine a 50-m circular area within your field of view, and use the illustrations in the guide to estimate a rating for karst roughness within that area. (A 25-m radius is considered the maximum visual distance for this purpose.)

Estimates for karst roughness are recorded at stops, and between stops along the traverse route. Karst roughness ratings are interpolated and/or extrapolated (within reasonable limits) to the ground not covered away from stops and routes.

The karst roughness rating is used to modify the surface karst sensitivity rating during the vulnerability assessment procedure (see Section 4.3.14, Figure 4.14). A karst roughness rating of high or very high raises the surface karst sensitivity rating by one category.

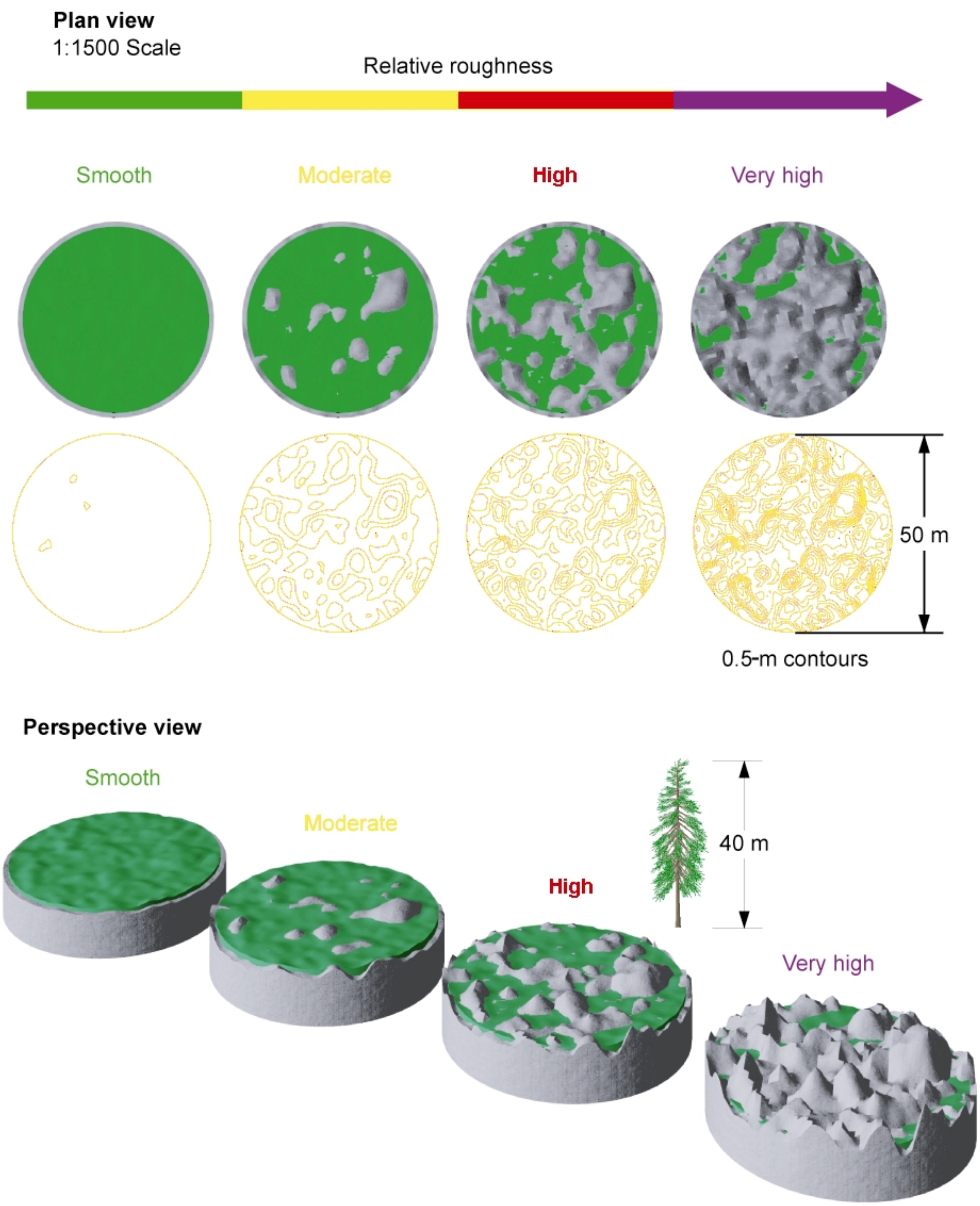


Figure 4.12. **Visual chart for determining karst roughness.**

4.3.9 Stream evaluations and hydrology

Due to their complexity and linear nature, streams flowing on karst are not directly incorporated into the vulnerability assessment process, which is an area-based procedure applied to karst polygons. However, streams are a critical component of the karst system that must be assessed, primarily because of the close hydrological links that can exist between the surface and subsurface.

Stream types

A variety of stream types can occur on karst terrain:

Surface streams – streams that flow in surface channels with minimal or no water loss to the subsurface.

Sinking streams – streams that disappear underground at a distinct sink point or swallet.

Losing streams – streams that gradually lose water through an unconsolidated alluvial channel bed, or through a series of small openings, fractures, or sink points.

Gaining streams – streams that receive additional water from underground sources.

Interrupted streams – streams where the flow sinks into the subsurface and returns to the surface with no apparent loss of overall flow.

Rising streams (karst springs) – underground streams that emerge at the surface through a spring.

Figure 4.13 illustrates the various types of streams found on karst terrain.

Purpose of stream evaluations

Stream evaluations on karst terrain are primarily concerned with:

- locating the points where water sinks underground; and
- determining the significance of the karst resources receiving the water (recipient karst features).

These two tasks are linked to the major management objectives for streams associated with karst:

- maintaining water quality and quantity of surface and subsurface streams; and
- limiting the introduction of sediment and woody debris (large and small) into the subsurface within the range of natural conditions.

Large woody debris and sediment can be transported downstream where it accumulates and clogs sink points. This can restrict water flow into the sink point 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 woody debris (e.g., needles, twigs, leaves) into subsurface cavities and caves by way of streams that sink into the ground at distinct points (sinking streams) or lose water through a series of small openings, fractures or sink points (losing streams). These materials can coat underground surfaces, thereby affecting subsurface habitats and other cave resources / values. The slow decay rate associated with underground environments in British Columbia allows the organic component of this material to persist over long periods of time.

Evaluating and mapping streams

The identification of sinking and losing streams is one of the primary tasks associated with stream assessments on karst terrain, since these types of streams have the potential to transport sediment and debris into sensitive subsurface environments. Sinking streams commonly occur along the upper boundary of a karst unit, while losing streams can occur at any location within a karst unit.

Continuous surface streams, sinking streams, and springs are readily apparent in the field. Losing streams can be identified by locating the small features where the water flows underground, or by observing a sudden drop in the volume of stream flow. Gaining streams can be identified by locating springs discharging flow into the stream from side banks, or by observing a sudden increase in the volume of stream flow.

All sink points, losing or gaining segments, and springs should be recorded, geo-referenced, and plotted on the map using RIC-approved symbols for stream types and hydrological features (see Figure 4.6).

Streams can be assessed as they are encountered during ground searching or at the end of a KFA, depending on the type of ground search, the type of features/terrain encountered, and the discretion of the field crew.

Any streams running parallel or sub-parallel to a proposed cutblock boundary that are identified in the 100-m extended area outside of the cutblock should also be assessed to determine if riparian management requirements for those streams would conflict with the proposed boundaries. Stream assessments should begin at a point approximating the closest downslope corner of the proposed cutblock and continue downstream for the appropriate distance recommended in the Stream assessment distances section (p. 60). Any recommended cutblock boundary changes resulting from the stream assessment should be marked in the field, designated on the map, and recorded in the KFA report.

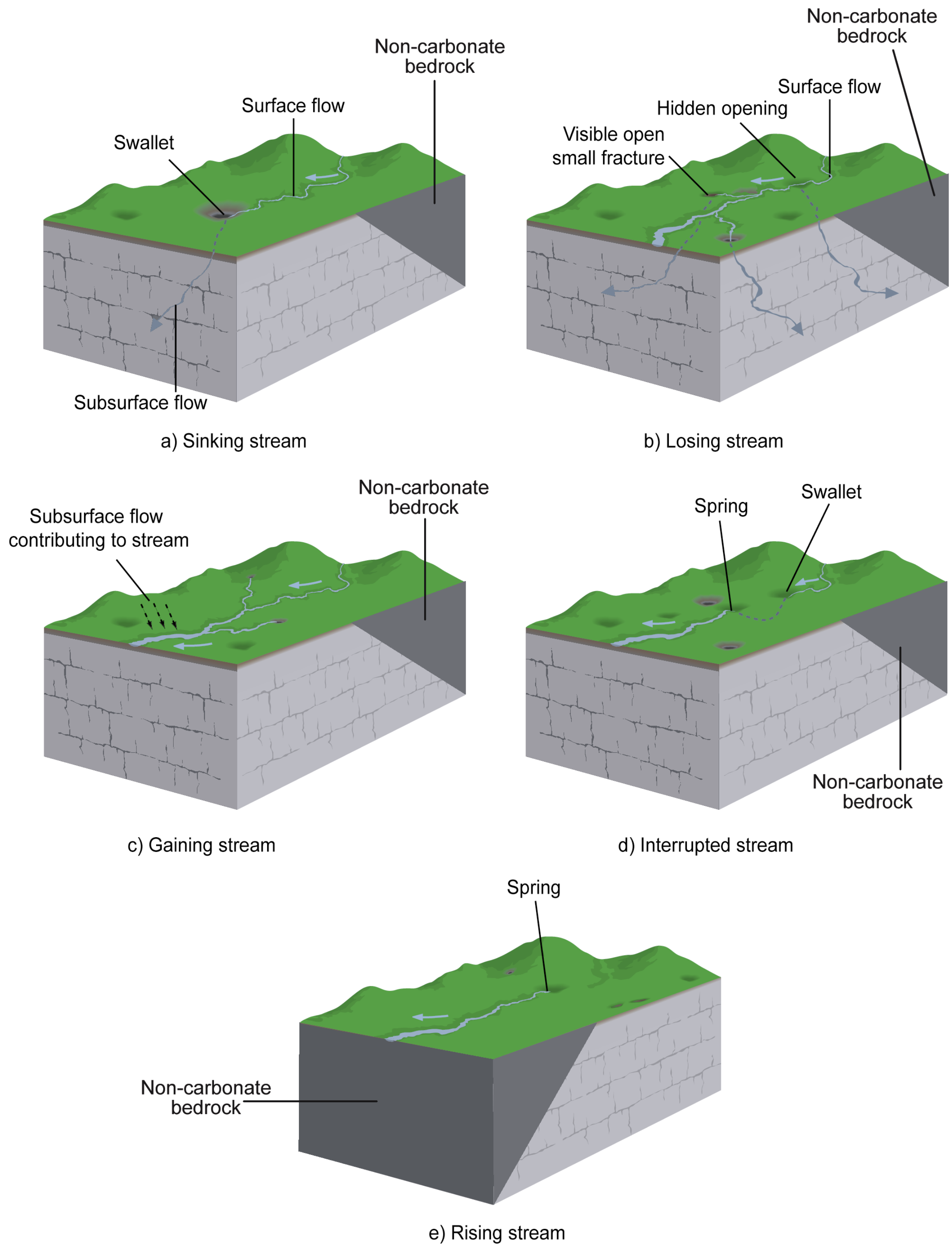


Figure 4.13. **Stream types and characteristics on karst terrain.**

Stream assessment distances

Stream assessment distances are based on the width of the stream, which is an indicator of the transport potential of the stream channel. 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 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.[17]

- Stream width <1.0 m (karst) or <1.5 m (non-karst): assess the stream along its entire length within the proposed area of development, and for a minimum of 250 m downstream of the development boundary or the point where the stream flows off karst terrain, whichever is shorter.
- Stream width 1.0–3.0 m (karst) or 1.5–3.0 m (non-karst): assess the stream along its entire length within the proposed area of development, and for a minimum of 500 m downstream of the development boundary or the point where the stream flows off karst terrain, whichever is shorter.
- Stream width >3.0 m: assess the stream along its entire length within the proposed area of development, and from the development boundary downstream to the last contact with carbonate bedrock. For streams of this size, the assessment should be able to be conducted predominantly as an office exercise using bedrock geology maps, air photos, existing field knowledge, local knowledge of the area, etc.

Determining the significance of recipient karst features

Where a stream assessment identifies a sinking or losing stream, the recipient karst feature must be assessed to determine its significance in order to assign appropriate surface management practices. The investigation of recipient karst features may require subsurface inspection, which is beyond the experience of most KFA personnel. Subsurface tasks should be assigned to individuals with specialized knowledge and training (see Section 4.3.10).

Sinking watercourses

The Forest Practices Code (FPC) defines a "stream" as a watercourse with a continuous channel of more than 100 m in length that exhibits evidence of scouring or alluvial deposition. While this definition can be applied to many of the 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 FPC definition for a stream (e.g., fail to meet the 100-m distance criterion). However, even though these types of watercourses do not meet the FPC definition for a stream, they still need to 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 FPC definition for a stream, watercourses of this type are referred to as "sinking watercourses" for the purposes of a KFA.

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[17] The procedures in this section have not been field tested, and are based on a limited understanding of the processes involved with the movement of fine particulate matter in streams flowing into recipient karst features. Further research into these processes is required in British Columbia. It is recommended that the suggested stream assessment distances be applied using an adaptive management approach, with the flexibility to adjust the assessment distances, if required, based on operational experience.

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:

- have no or poorly 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 m.

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).

Sinking watercourses are considered to be less of a management concern than sinking streams because of their generally lower potential for affecting significant recipient karst features (i.e., sinking watercourses would typically exhibit low-energy water flows, lower transport potential, intermittent or ephemeral flows, etc.).

When numerous watercourses are encountered in the field, it is not necessary to follow them to assess whether they sink or not. Ground searching efforts are instead concentrated on locating recipient karst features. When a significant recipient karst feature receiving water from a sinking watercourse is located, the feature is recorded, geo-referenced, and mapped, and the sinking watercourse receives an appropriate level of riparian management as recommended in the *Karst Management Handbook for British Columbia*.

As with the inventory procedures for streams, the procedures for sinking watercourses have not been field tested, and are based on a limited understanding of the processes involved with the movement of fine particulate matter in watercourses flowing into recipient karst features. Further research into these processes is required in British Columbia. It is recommended that the suggested procedures in this section be applied using an adaptive management approach, with the flexibility to adjust the procedures, if required, based on operational experience.

Delineating catchment areas

For management purposes, the area contributing water to significant recipient karst features and significant karst springs needs to be delineated.

This process is relatively straightforward for significant recipient karst features, as the sinking and/or losing streams (or sinking watercourses) contributing water to these features are primarily fed by surface runoff from the contributing non-karst catchment area. The boundaries of the contributing non-karst catchment area can be readily defined by topographic divides.

Karst springs can be recharged by diffuse infiltration through contributing karst catchments, by surface runoff from sinking and/or losing streams (or sinking watercourses) flowing off contributing non-karst catchments, or through a combination of the two. Delineating diffuse recharge areas can be a complicated process because the water rapidly infiltrates the ground and cannot be traced over the surface. Furthermore, diffuse recharge for a particular karst unit or system may occur in more than one topographic basin, and, unlike non-karst catchments, contributing areas cannot be reliably inferred from local topography. Dye tracing and other hydrogeologic investigations are often required to delineate diffuse recharge areas. Due to the complexity of delineating diffuse recharge areas, this type of work should be overseen by experienced professionals (see following section).

Dye tracing and other karst water data

Dye tracing can be an important tool for investigating the subsurface hydrology of karst systems. Details on dye tracing procedures are outlined in Section 3.3.4 and can be found in Stokes and Griffiths (2000) and the *Groundwater Tracing Handbook* (Aley 1999). Dye tracing is carried out using one or more fluorescent dyes that are injected into a recharge site (e.g., sinking stream), and then tracked through sampler sites located at likely discharge locations (e.g., springs). Dye tracing investigations can range from relatively straightforward procedures, such as confirming the emergence point for a sinking stream, to more complex studies, such as delineating diffuse recharge areas. Since flows in karst systems can be highly variable, dye tracing may be required at a number of different stages or times throughout the year to obtain accurate information.

Limited, straightforward dye tracing studies can be designed and carried out by experienced KFA field crews. Complex, larger-scale dye tracing projects should be overseen by experienced professionals.

A number of other data measurements (e.g., conductivity, pH, temperature, dissolved oxygen content, and flow rate) can be collected along streams or at sinking/emerging points to provide additional information on the karst hydrological system.

Conductivity (or specific conductance) is one of the most useful measurements, particularly for identifying and mapping the presence of karst waters, and in the design and interpretation of dye tracing results (see Stokes et al. 1998). Specific conductance measures the ability of water to conduct electricity at a standard temperature. In general, the longer water has been in contact with carbonate bedrock, the greater its specific conductance. Typically, waters occurring within or downstream of karst areas give high conductance values (e.g., >80 micromhos/cm), while waters draining non-karst areas give lower values (e.g., <30 micromhos/cm). High or low conductance values can also give some indication as to whether a deep or shallow hydrological system is present—higher values indicate a deeper system. A standard lightweight conductivity meter can be used for this purpose.

The use of a pH meter can be useful for determining if water has been in contact with karst. Karst waters typically have pH values of 7–8; however, readings can be slightly lower if acidic waters from non-karst bedrock or organic-rich areas (e.g., upland swamps) have been introduced. Measurements of pH can also be important for the analysis of dye tracing data.

Water temperature measurements can be useful under certain conditions, but can be affected by localized variables such as snowmelt or microclimatic changes along the stream. During hot weather conditions, water temperature measurements can be useful for identifying water derived from karst springs, as temperatures are likely to be cooler than the surrounding surface flows.

Flow rate estimates can be useful to characterize and determine the significance of hydrological features (e.g., swallets and springs). This information is also useful in dye tracing tests. Flow rates can be estimated using channel cross-sectional areas and flow velocities. Since flows in karst systems can be highly variable, measurements are often required at a number of stages or times throughout the year to obtain accurate information.

4.3.10 Subsurface inspection and mapping

When caves are encountered during a KFA, subsurface inspection and mapping are used:

- to assess the caves for their significance;

- to collect survey data to establish the three-dimensional location of the cave system with respect to the surface; and
- to help determine the subsurface karst potential for the area (see Section 4.3.11).

Caves or suspected caves identified during a KFA need to be inspected and classified to determine their significance in order to assist with appropriate surface management decisions. However, caves can be hazardous[18] and/or sensitive environments. Steep cave entrances and interior passages should be inspected and classified only by experienced personnel. In many cases, field workers carrying out a KFA will not be qualified or suitably equipped to safely inspect caves, and individuals with specialized knowledge or training may be needed for this task.

The inspection and classification of caves is a detailed inventory in its own right, and is not described in this document. Personnel inspecting caves as part of a KFA should refer to the *Cave/Karst Management Handbook for the Vancouver Forest Region* (B.C. Ministry of Forests 1994) for guidance.

In many cases, surveying and mapping of caves is required to determine their three-dimensional location with respect to the surface prior to the initiation of road construction or timber harvesting (e.g., to establish the thickness of the ceiling and the underground orientation of the cave relative to the area of development).

For some sites, cave maps may already be available through Forest Service district offices or caving organizations. Where caves have not been previously mapped, surveying and mapping will need to be completed for at least those portions of the cave that underlie the area of proposed development. For relatively small caves, it may be practical to survey and map the entire cave at one time. More complex caves may extend somewhat beyond the area of proposed development. For larger cave systems, surveying and mapping only those areas of the cave that underlie the area of proposed development may be a more practical and cost-effective approach.

When caves or suspected caves are identified during a KFA, the location of the entrance should be plotted on the base map, along with the outline of any known cave passages. This information should also be added to the database of the appropriate planning-level inventory, if one has been completed for the area. All subsurface inspection and mapping should be referred to experienced specialists.

Cave survey and mapping information can also be used to help determine subsurface karst potential ratings (see Section 4.3.11).

4.3.11 Subsurface karst potential

Subsurface karst potential is an interpretation of the three-dimensional nature of a karst unit, and can be estimated qualitatively by assessing a number of karst attributes within an area of interest. Experience from similar karst areas can also be used to assist in determining the subsurface karst potential of an area.

The major attributes used to determine subsurface karst potential include:

- surface watercourses and their characteristics;
- known caves or suspected caves; and
- large-scale negative relief features.

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[18] For cave rescues and other emergencies, call the local RCMP or the PEP Emergency Coordination Centre at 1-800-663-3456.

The assessment of subsurface karst potential is based on the presence or absence of caves, the presence or absence of large-scale negative relief features, and the presence or absence of surface watercourses (and their characteristics when present). These three factors assess the potential level of karst development in the endokarst, which is the deeper karst that lies beneath the epikarst.

Table 4.3 provides criteria for determining subsurface karst potential. Where subsurface inspection and mapping has been carried out, this information can be used to confirm or adjust subsurface karst potential ratings.

The presence of caves indicates a well-developed endokarst.

The presence of large-scale negative relief features (e.g., large sinkholes, dry valleys) can indicate a high level of connectivity with the subsurface and/or subsurface flow at depth.

Surface watercourses with no evidence of water loss or gain generally indicate little or no subsurface drainage development; losing or gaining watercourses generally indicate the presence of a shallow subsurface drainage system; sinking or rising watercourses generally indicate the presence of a moderately developed subsurface drainage system; and the absence of surface watercourses indicates a well-developed subsurface drainage system.

Subsurface karst potential ratings —low, moderate, or high—are combined with surface karst sensitivity ratings to determine final vulnerability ratings for karst polygons (see Section 4.3.14, Figure 4.14).

Subsurface karst potential ratings are generally derived as an office-based exercise after reviewing all available data.

With experience, KFA field workers will also be able to interpret other karst attributes and field data to assist in determining subsurface karst potential (e.g., locations of swallets/springs, evidence of subsurface water flow).

Table 4.3. **Criteria for determining subsurface karst potential**

Subsurface karst potential	Caves	Large-scale negative relief features*	Surface watercourses
Low	No known caves	No large-scale negative relief features	Surface watercourses present with no evidence of water loss or gain
Moderate	Evidence of caves or suspected caves (possible cave entrances)	At least one large-scale negative relief feature	Losing and/or gaining watercourses present OR Sinking and/or rising watercourses present
High	Known caves	More than one large-scale negative relief feature	No surface watercourses

* e.g., sinkholes with mean diameters >20 m; dry valleys

4.3.12 Unique or unusual karst flora and fauna

The identification of unique or unusual karst flora or fauna can be carried out by either identifying individual species or recognizing favourable habitats (see Table 3.8). The recognition of karst biota by individual species may require specialized expertise and a detailed knowledge of plant and animal taxonomy (see Tables A1 and A2 in Appendix A). This is generally beyond the scope of most KFA crews. For assistance in identifying or confirming species, contact the Conservation Data Centre at http://srmwww.gov.bc.ca/cdc/request.htm.

A more practical alternative to identifying karst biota by species is to recognize possible favourable habitats. In general, suitable habitats for karst flora in forested terrain (closed canopy) include sites that are moist and shaded, with shallow soils, particularly along the coast. Examples of these types of habitats include zones of well-developed epikarst, grikes, along karst bluffs or canyons, and around large and/or deep sinkholes, swallets, springs, and cave entrances.

Karst flora can also be found in open-canopy sites, both on forested slopes and at higher elevations (subalpine/alpine locations). These sites are typically well drained, with thin soils over carbonate bedrock, and are exposed to sunlight. Sites such as these can display a considerable diversity of karst-related flora. Karst springs and calcium-rich seeps (e.g., tufa) can provide very distinctive sites for karst-specific flora (e.g., giant helliborine orchids, [*Epipactis gigantean*]).

The main focus for identifying karst fauna is on the surface and, in some cases, the twilight zone of caves and other cavities. Inventory of fauna in the dark zone of karst cavities and caves is a highly specialized field, and beyond the scope of a KFA. The publication *Caves and Cave Life*, by P. Chapman (1993), provides a straightforward reference on cave and karst fauna.

One of the principal mammals associated with karst caves are bats. Bats are known to use caves for maternity and hibernation colonies in a number of locations in British Columbia (e.g., Weymer Creek Caves on Vancouver Island). Standards for conducting bat surveys are outlined in *Inventory Methods for Bats* (RIC, 1998). Other mammals, such as black-tailed deer, weasels, marten, and shrews, are also known to use karst features for habitat (S. Rasheed, pers. comm., 2000).

Most insect associations with karst are confined to cavities and caves, or springs. However, certain moths and butterflies are known to associate with limestone surfaces where greater plant diversity is present. For example, the butterfly species *Boloria natazhati* is specifically linked to limestone terrain in the northern interior of British Columbia (C. Guppy, pers. comm., 2000).

In British Columbia, salmon and/or trout have been observed in karst caves on Vancouver Island, Moresby Island, and Princess Royal Island, but the nature of this association has not been scientifically investigated. However, there is documented evidence for an increase in productivity and population size of coho salmon in karst terrain in southeast Alaska (Bryant et al. 1998).

When unique or unusual karst biota or favourable habitats are identified during a KFA, the location of the site is recorded and mapped, along with a detailed description of what was encountered. If karst flora/fauna or habitat sites are considered significantly large, unusual, or rare, they are utilized to influence the vulnerability rating of a karst polygon (see Section 4.3.14, Figure 4.14). Where karst flora/fauna/habitat sites are dispersed over the polygon, increase the vulnerability rating by one category. Where karst flora/fauna/habitat sites are contained in small, localized areas, establish smaller polygons for those areas.

4.3.13 Geomorphic hazards

During a KFA, geomorphic hazards that could potentially affect the karst area of interest should be identified. These hazards can be the result of natural disturbances or human activities, and primarily include those hazards related to landslides, gully sidewall and channel erosion, windthrow, fire/burned areas, and surface flooding.

The location, type, and possible extent of geomorphic hazards are recorded, potential consequences to the karst unit assessed, and the need for further investigation determined. It is not the intent of a KFA to fully evaluate geomorphic hazards, but rather to identify them for evaluation by others with experience in this area (e.g., geoscientists or geotechnical engineers).

Procedures for evaluating geomorphic hazards, such as landslides and soil erosion, are included in the *Gully Assessment Procedures Guidebook*, the *Hazard Assessment Keys for Evaluating Site Sensitivity to Soil Degrading Processes Guidebook*, and the *Mapping and Assessing Terrain Stability Guidebook*. Procedures for windthrow evaluation are included in the *Windthrow Handbook for British Columbia Forests* (Stathers et al. 1994) and in a recent paper on windthrow risk by Mitchell (1998).

Information collected on geomorphic hazards is not included in the vulnerability assessment process; however, it is recorded for consideration in surface management decisions (see KFA Field Card #3 in Appendix F).

4.3.14 Karst vulnerability assessment

The karst vulnerability assessment is the final part of a KFA, and provides one of the critical links between a karst inventory and the management recommendations outlined in the *Karst Management Handbook for British Columbia*. The underlying goal of the karst vulnerability assessment process is to qualitatively integrate the surface and subsurface data collected during the KFA to derive a vulnerability rating for the karst area within a specific karst polygon. This is carried out using a four-step procedure that results in one of four possible karst vulnerability ratings– low, moderate, high, or very high.

Four-step vulnerability procedure

The four-step vulnerability assessment procedure, summarized in Figure 4.14, is a systematic method for determining a vulnerability rating for a karst polygon using three major criteria: epikarst sensitivity, surface karst sensitivity, and subsurface karst potential. The procedure also allows for the integration of three modifying factors: fine-textured, erodible soils; karst roughness; and unique or unusual karst flora/fauna sites.

Step I considers the level of *epikarst development*, derived from the frequency of vertical solutional openings versus their average depth to obtain a rating for epikarst development – low, moderate, high, or very high.

Step II integrates the epikarst development rating with the average soil thickness covering the epikarst to obtain a rating for *epikarst sensitivity*–low, moderate, high, or very high. At this step, a modifier can be incorporated for the presence of fine-textured, erodible soils, which can increase the epikarst sensitivity rating by one category.

Step III integrates the rating for epikarst sensitivity with the density of surface karst features to provide a rating for *surface karst sensitivity*–low, moderate, high, or very high. A modifier for karst roughness can be incorporated at this step. If a high or very high level of karst roughness is evident, the surface karst sensitivity rating is raised by one category.

Step IV, the final step, adds the third dimension to the karst polygon by introducing a rating for *subsurface karst potential*, which is integratd with the rating obtained for surface karst sensitivity. This integrated rating represents the sensitivity of the *total karst system* for the polygon. A modifier for the presence of unique or unusual karst biota or favourable habitats can be incorporated at this step. If a unique or unusual habitat site for karst flora/fauna is present, the overall karst vulnerability rating is increased by one category.The vulnerability assessment procedure can be conducted in the field using KFA Field Card #3 from Appendix F, or in the office after the field work has been completed.

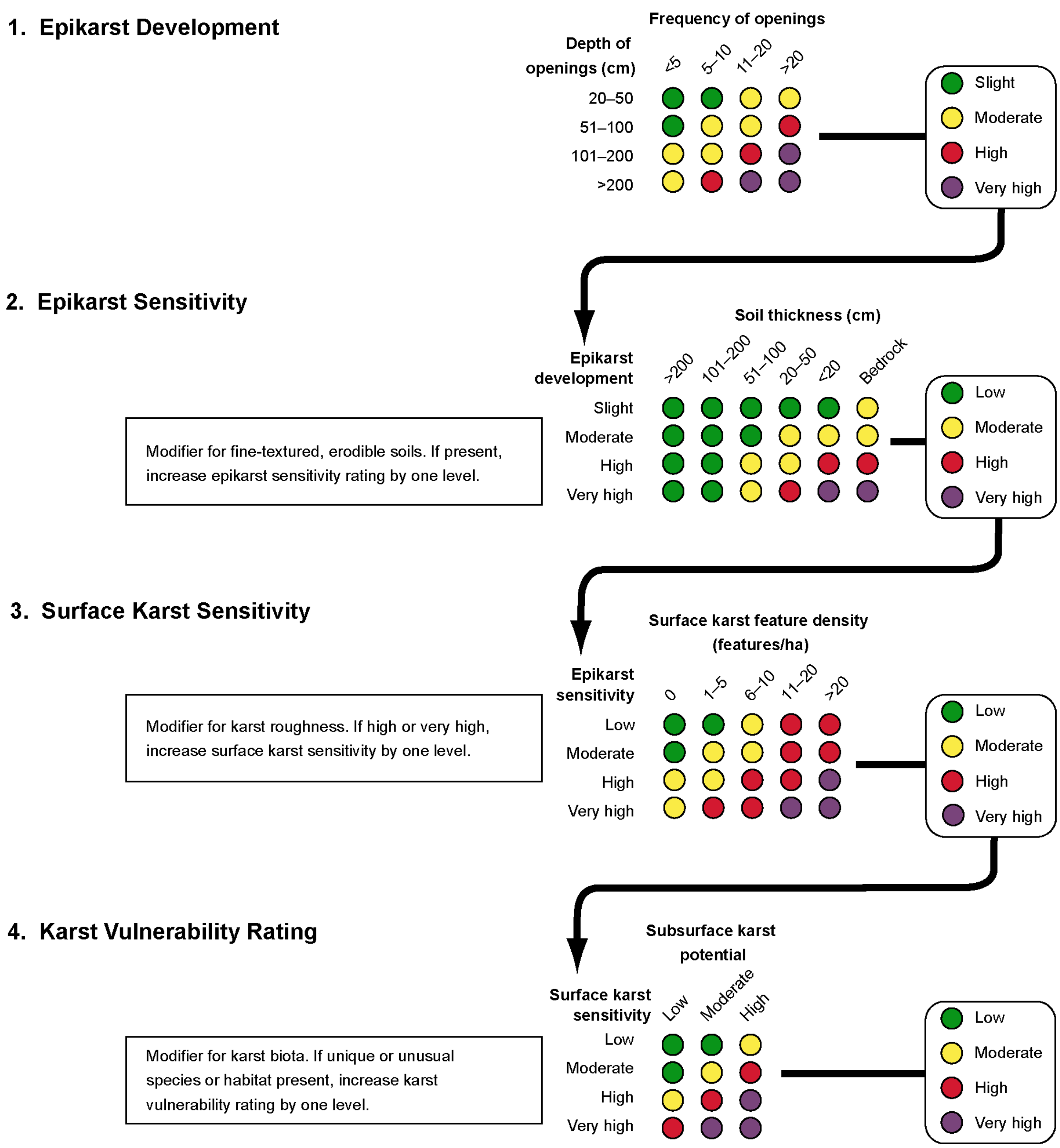


Figure 4.14. **Karst vulnerability assessment procedure.**

4.4 Standards for KFA Reports and Maps

4.4.1 Reports

KFA reports should follow the standard technical report format (i.e., introduction/background, methods, results, recommendations, appendices, etc.).

The results section of the report should include:

- a description of the level of epikarst development, soil thickness, surface karst feature density, karst roughness, unique or unusual karst flora/fauna, subsurface karst potential (including caves), surface streams, significant surface karst features, plus any other notable/special features or attributes;
- the vulnerability ratings for each karst polygon in the KFA area; and
- a description of any geomorphic hazards that could potentially affect the KFA area.

The recommendations section should include recommended management strategies or mitigative measures, including rationales.

KFA reports should be written in technically accurate language that is understandable to a wide range of readers, from management to field staff.

4.4.2 Maps

The data from a KFA should be organized and presented spatially on a map. Final map data will generally be produced in a GIS or other digital system format. Manual maps may be acceptable in some cases, but are of less use where integration into other data systems is required.

Map elements/layers should include:

- title, legend, scale, north arrow
- cutblock boundaries (proposed, existing)
- roads (proposed, existing) and skid trails
- other administrative boundaries (e.g., parks)
- contours
- lakes, streams, wetlands
- final KFA unit boundary
- karst polygons (with vulnerability ratings)
- karst features (point and linear), feature clusters, and zones of intense epikarst development
- cave passage outlines for larger caves
- bedrock geology and contacts
- subsurface flow paths (inferred or dye traced)
- epikarst and surface karst feature calibration plots
- ground search routes and stops
- other notable/special features (culturally modified trees, bear dens, etc.)

4.4.3 Information management

Procedures should be developed to ensure that sensitive karst inventory data (e.g., cave entrance locations) are kept secure. A secure/coded layer could be developed within a GIS for cave locations to allow access to only specified personnel.

On TFLs, information regarding specific karst features that may require special management as recreation features should be incorporated directly into the recreation resources inventory by the licensee. The local forest district office should be notified when this occurs. On TSAs, this type of information should be directed to the local forest district office for input into the recreation features inventory.

4.5 KFA Personnel Qualifications and Training

The following qualifications should be used as general guidelines for personnel completing KFAs. These qualifications will vary depending on whether personnel are responsible for coordinating, directing, or performing the inventory work. Various combinations of training, experience, and ability will have a bearing on qualification requirements.

Persons coordinating or directing field inventories should have an appropriate combination of post-secondary education and experience, and be well versed in karst processes. They should be familiar with designing inventory procedures, mapping techniques, conducting karst field work, data analysis, and completing technical reports and maps. It is suggested that these people be registered professionals (e.g., RPF, PGeo, RPBio, PAg, PEng) who have successfully supervised a number of karst inventory projects in British Columbia or have undergone karst inventory training.

Experienced forest technicians or engineers familiar with karst systems and processes are good candidates for KFA crews. With appropriate training, these types of personnel could effectively perform the required field tasks and assessments associated with KFAs.

In special cases, there may be a need to assemble a multi-disciplinary team for more detailed inventories of significant karst ecosystems encompassing multiple resources and values. Specialists for these kinds of inventories could include geomorphologists, hydrogeologists, biologists, paleontologists, archaeologists, etc., as required by site-specific conditions.

Experienced cavers or personnel familiar with working safely in subsurface environments may be required for evaluating and mapping caves and other cavities. More knowledgeable and experienced speleologists would likely be required for the safe and efficient investigation of technically difficult and/or sensitive caves.

5.0 References

Aley, T. 1999. Groundwater tracing handbook. Ozark Underground Laboratory, Protem, Mo.

B.A. Blackwell and Associates. 1995. Literature review of management of cave/karst resources in forest environments. Prepared for B.C. Min. For., Vancouver Forest Region, Nanaimo, B.C. Unpubl. rep.

Bryant, M.D., D.N. Swanston, R.C. Wissmar, and B.E. Wright. 1998. Coho salmon populations in the unique landscape of North Prince of Wales Island, Southeast Alaska. Amer. Fisheries Soc. 127: 425–433.

Chapman, P. 1993. Caves and cave life. Harper Collins, New York, N.Y.

Chatwin, S. 1999. Karst vulnerability assessment procedure. B.C. Min. For., Res. Br., Victoria, B.C.

Chatwin, T.A., M. Davis, and D. Nagorsen. 1997. Bat usage of the Weymer Creek cave systems on northern Vancouver Island, Canada. Proc. symp. on Karst and Cave Management. Oct. 1997. Bellingham, Wash.

Douglas, G. 1998. Rare native vascular plants of British Columbia. Min. Environ., Lands and Parks, Victoria, B.C.

Ford, D.C. and P.W. Williams. 1989. Karst geomorphology and hydrology. Unwin Hyman Ltd, London, U.K.

Griffiths, P. 1993. Classification system for discrete mesoscale and microscale surface karst features. Unpubl. paper.

———. 1997. Searching for cave entrances in old-growth forests: an overview of ground-based methods employed in north and central Vancouver Island, British Columbia. Proc. symp. on Karst and Cave Management. Oct. 1997. Bellingham, Wash.

Harding, K.A. and D.C. Ford. 1993. Impacts of primary deforestation upon limestone slopes in Northern Vancouver Island, British Columbia. Environ. Geol. 21:137–143.

Holsinger, J.R. 1981. *Stygobromus canadensis*, a troglobitic amphipod crusteacean from Castleguard Cave, with remarks on the concept of cave glacial refugia. 8th Proc. Internat. Speleological Congress, Bowling Green, Ky. pp. 93–95.

Holsinger, J.R. and D.P. Shaw. 1987. *Stygobromus quatsinensis*, a new amphipod crustacean (Crangonyctidae) from caves on Vancouver Island, British Columbia, with remarks on zoogeographic relationships. Can. J. Zool. 65:2202–2209.

Howes, D.E. and E. Kenk. 1988. BC terrain classification system. B.C. Min. Environ., Lands and Parks, Victoria, B.C.

Jennings, J.N. 1985. Karst geomorphology. Basil Blackwell, Oxford, U.K.

Kiernan, K. 1990. Soil and water degradation in carbonate rock terranes. Austral. J. Soil and Water Conserv. 3(4):26–33.

Mitchell, S.J. 1998. A diagnostic framework for windthrow evaluation. For. Chron., Vol. 74, No. 1. pp. 100–105.

Nagorsen, D.W., A.A. Bryant, D. Kerridge, G. Roberts, A. Roberts, and M.J. Sarell. 1993. Winter bat records for British Columbia. Northwest Nat. 74:61–66.

Pojar, J. and A. MacKinnon. 1994. Plants of coastal British Columbia. Lone Pine Publishing, Vancouver, B.C. p. 425.

B.C. Ministry of Forests. 1994. Cave/karst management handbook for the Vancouver Forest Region. B.C. Min. For., Victoria, B.C.

———. 1995a. Gully assessment procedures guidebook. 3rd ed. B.C. Min. For., Victoria, B.C.

———. 1995b. Hazard assessment keys for evaluating site sensitivity to soil degrading processes guidebook. B.C. Min. For., Victoria, B.C.

———. 1995c. Mapping and assessing terrain stability guidebook. B.C. Min. For., Victoria, B.C.

———. 1997. Karst in British Columbia: A complex landscape sculpted by water (brochure). B.C. Min. For., Victoria, B.C.

———. [2003]. Karst management handbook for British Columbia. B.C. Min. For., Victoria, B.C. In prep.

Resources Inventory Committee (BC). 1996a. Guidelines and standards for terrain mapping in British Columbia. Resource Inventory Committee BC, Victoria, B.C.

———. 1996b. Specifications and guidelines for bedrock mapping in British Columbia. Resource Inventory Committee BC, Victoria, B.C.

———. 1997. Terrain classification system for British Columbia. Resource Inventory Committee BC, Victoria, B.C.

———. 1998. Inventory methods for bats. Resource Inventory Committee BC, Victoria, B.C.

Scofield, W.B. Some common mosses of British Columbia. 1992. Royal British Columbia Museum Handbook No. 28 (2nd ed.). Victoria, B.C.

Stathers, R.J., T.P. Rollerson, and S.J. Mitchell. 1994. Windthrow handbook for British Columbia forests. B.C. Min. For., Victoria, B.C. Work. Pap. 94/01.

Stokes, T.R. 1996. A preliminary problem analysis of cave/karst issues related to forestry activities on Vancouver Island. B.C. Min. For., Vancouver Forest Region, Nanaimo, B.C. Unpubl. rep.

———.1999. 1:250 000 karst potential maps of British Columbia. B.C. Min. For., Res. Br., Victoria, B.C.

Stokes, T.R., T. Aley, and P. Griffiths. 1998. Dye tracing in forested karst terrain: A case study on Vancouver Island, British Columbia. *In* Post-conference Proc. 8th Internat. Assoc. Geological Engineers. September 1998. Vancouver, B.C.

Stokes, T.R. and P. Griffiths. 2000. A preliminary discussion of karst inventory systems and principles (KISP) for British Columbia. B.C. Min. For., Res. Br., Victoria, B.C. Work. Pap. 51. (www.for.gov.bc.ca/hfd/pubs/docs/wp/wp51.htm).

Vitt, D.H., J.E. Marsh, and R.B. Bovey. 1988. Mosses, lichens and ferns of northwest North America. Lone Pine Publishing, Edmonton, Alta.

White, W.B. 1988. Geomorphology and hydrology of carbonate terrains. Oxford University Press, Oxford, U.K.

White, W.B., D.C. Culver, J.S. Herman, T.C. Kane, and J.E. Mylroie. 1995. Karst lands. Amer. Scient., Vol. 83. p. 450–459.

6.0 Glossary

NOTE: Definitions for surface karst features are not provided in this glossary; those terms are defined in Appendix D.

Carbonate bedrock – rock consisting mainly of carbonate minerals, such as limestone or 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.

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

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

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 that collect and transport surface water and nutrients underground; epikarst depth can range from a few centimetres to tens of metres.

Geomorphic – pertaining to landforms and landscapes.

Gypsum – the mineral, hydrated calcium sulphate.

Interbed – a typically thin bed of rock material alternating with contrasting thicker beds.

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.

Karstification – action by water, mainly chemical but also mechanical, that produces features of a karst topography, including sinkholes, shafts, and caves.

Limestone – a sedimentary rock consisting mainly of calcium carbonate.

Lithology – the physical characteristics and description of bedrock types.

Marble – limestone recrystallized and hardened by pressure and heat.

Physiographic – pertaining to the origin and evolution of landforms.

Slikensides – rock surfaces on either side of a fault plane that have been polished or marked by friction between the moving blocks.

Speleology – the study of caves and their environments.

Transect – a transverse line; a line that crosses from side to side.

Tufa – soft, porous calcium carbonate deposited in solution from springs or surface waters.

Windthrow – uprooting of trees by the wind.

Appendix A. Karst flora and fauna

Table A1. **List of species and selected names of fauna associated with karst terrain, with a particular emphasis on British Columbia**

NOTE: The intent of this list is not to cover all karst fauna, but rather to display examples of possible species, so as to illustrate the complexities of life that can exist in karst terrain both on the surface and subsurface.

Fauna	Names, description, and general information
Bacteria	Typical examples occur within caves as "moonmilk"—a calcareous deposit, orange iron and black manganese stains and rarer yellow sulphur deposits
Fungi	Variety of mushrooms
Protista	—
Porifera and Bryozoa	Sponges rarely found
Turbellaria	Flatworns, numerous types found
Nematoda	—
Annelida	Segmented worms
Mollusca	Bivalvia and Gastropoda (freshwater shelled organisms)
Arachnida	Numerous types found. Harvestman spiders are common in many caves on Vancouver Island and the mainland
Crustacea	
Amphipod	*Stygobromus quatsinensis*—found on Vancouver Island (Holsinger and Shaw 1987). Also known on other coastal islands up to the Alaskan panhandle. *Stygobromus canadensis*—an amphipod from Castleguard Cave (Holsinger 1981)
Symphyla and Chilopoda	Centipedes
Diplopoda	Millipedes
Insecta	Common in most caves, and includes Collembola (springtails), Diptera (flies, gnats), and Coleoptera (beetles). A greater diversity of butterflies and moths occur over limestone terrain, probably a function of increased plant diversity. One butterfly species, *Boloria natazhati,* in northern British Columbia is known to have a direct association with limestone.
Submariners	Any fauna associated with coastal caves or openings
Amphibians	—
Fish	In British Columbia, salmon and/or trout have been observed in karst caves on Vancouver Island, Moresby Island, and Princess Royal Island, but the nature of this association has not been scientifically investigated. However, there is documented evidence for an increase in productivity and population size of coho salmon in karst terrain in southeast Alaska (Bryant et al. 1998)
Birds	—

Fauna	Names, description, and general information
Mammals	
Bats	Karst/cave systems are used by bats, particularly for maternity and hibernating colonies. A red-listed species, *Myotis keenii,* is known to occur within the Weymer Creek Cave system on Vancouver Island (Chatwin et al. 1997). Additional bat species associated with karst in British Columbia include *M. lucifugus, M. thysanodes, Corynorninus townsendii,* and *M. septentrionalis*. Nagorsen et al. (1993) lists all winter bat records for British Columbia in both caves and mines, some of which may be in karst
Other mammals	Karst and its associated surface or near-surface features (particularly on the north of Vancouver Island) may also provide habitat for a number of other mammals, such as deer, weasels, martens, and shrews

Table A2. **List of species and selected names of flora associated with karst terrain, with a particular emphasis on British Columbia**

NOTE: The intent of this list is not to cover all karst flora, but rather to display examples of possible species, so as to illustrate the complexities of life that can exist in karst terrain.

Flora	Description
Trees	No types known to be specifically associated with limestone bedrock.
Shrubs	No types known to be specifically associated with limestone bedrock.
Wildflowers	
Epipactis gigantea	A red-listed orchid found around calcium-rich seeps (e.g., Pilot Peninsula, Kootenay Lake).
Grasses	No types known to be specifically associated with limestone bedrock.
Ferns	
Asplenium virde (green spleenwort)	Calciphile found on moist and shaded vertical bedrock faces or crevices, middle to alpine elevations (Pojar and MacKinnon 1994).
Asplenium adulterinum	A blue-listed fern found on central Vancouver Island (Clayoquot Plateau and Tahsis Mountain) and in the Pierce Range. Habitat is on dry to mesic walls of limestone fissures in subalpine zones (Douglas 1998).
Hedysarum occidentale	Occasionally found on karst, such as Marble Meadows, Vancouver Island (Douglas 1998).
Bryophytes (Mosses and Liverworts)	
Hypopterygium fauriei	See Scofield 1992.
Fissidens limbatus	See Scofield 1992.
Preissia quadrata	See Scofield 1992.
Lichens	See Vitt et al. 1988.
Aquatics	—

Appendix B. Karst and related attributes requiring identification, location, and measurement during a planning-level inventory

NOTE: Not all of these attributes need to be examined extensively; the list simply illustrates which attributes should be considered during the inventory work.

Karst attribute	Data collection requirements
Bedrock Geology	
Karst lithology	Type (e.g., limestone, dolomite, gypsum). Form (e.g., massive, interbedded) and proportion. (*See Table 3.2)*
Other lithology	Types (e.g., volcanics, intrusives) and contact relationship (e.g., faulted, intrusive, gradational).
Karst unit boundary	Where possible, locate to the nearest 25 m. Mapped using standard line notation for defined, approximate, and assumed.
Extent of bedrock exposure	Mapped using standard conventions (e.g., dotted line or “x” for small).
Bedding planes	Dip and strike measured by compass using standard geological procedures (Right Hand Rule).
Major faults	Dimensions and description. Strike/dip of fault plane, offset direction, slikensides.
Major folds	Size. Orientation of fold axis and axial plane. Type (e.g., anticline or syncline).
Minor faults	Dimensions and description. Strike/dip of fault plane, offset direction, slikensides.
Minor folds	Size. Orientation of fold axis and axial plane. Sense of movement.
Joint sets	Orientation, spacing, and openness.
Slope Geomorphology and Surficial Materials	
Slope gradient class	Measure gradient in percent. See *Terrain Classification System for British Columbia.*
Slope topography	Slope position (e.g., mid, upper, or lower slopes), form (e.g., uniform, concave, irregular, straight).
Karst micro-topography	Local small-scale topography reflecting karst processes. *(See Table 3.3)*
Surficial type and materials	Type (e.g., moraine, fluvial, colluvium), texture (e.g., silty or sandy) thickness (e.g., very thin veneer <0.2 m, veneer <1 m, blanket >1 m, or mantle), weathering depth. See *Terrain Classification System for British Columbia.*
Slope drainage	Rapidly, well, moderately well, poorly, or very poorly drained. See *Terrain Classification System for British Columbia*.
Forest floor / organic layer	Type, texture and depth. See *Terrain Classification System for British Columbia.*
Surface Karst Features – See Appendix D and Figure 4.6 for details.	
Streams and Hydrological Features – See Appendix D and Figure 4.6 for details.	
Geomorphic Hazards and Natural Disturbances	
Fire/burn areas	Extent and intensity.
Tree windthrow	Orientation, age, extent, and species.

Karst attribute	Data collection requirements
Landslides	Location, size, and materials.
Rockfall and soil slumps	Location, size, and materials.
Gully sidewall and channel erosion	Location, size, and materials.
Surface flooding	Level, size, and frequency.
Karst Flora and Fauna – See Appendix A and Table 3.8.	
Unusual plants or plant communities	Species, location, and extent.
Unusual fauna or evidence of fauna	Species, location, and extent.
Favourable flora habitat	Location and extent.
Favourable fauna habitat	Location and extent.
Karst Air – See Appendix C (re: connectivity).	
Slope aspect	Azimuth.
Drafting around cave entrances	Amount and direction.
Air temperature around surface karst depressions, openings and cave entrances	Estimates of maximum, minimum, and mean.

Appendix C. Procedure for determining surface karst feature significance

Introduction

The procedures outlined here are largely based on *Classification System for Discrete Mesoscale and Microscale Surface Karst Features* (Griffiths 1993). Significant surface karst features are critical components of the karst system that can be negatively affected by development activities (e.g., forest harvesting or road construction). These impacts can, in many cases, be transmitted to other parts of the karst system (e.g., the movement of logging debris from a sink point into cave passages).

Significant surface karst features can include sinkholes, shafts, grikes, swallets, bluffs, canyons, springs, cave entrances, etc. Determining the significance of surface karst features requires a qualitative evaluation of a number of criteria. These criteria include: dimensional characteristics; connectivity; hydrology; geological values; biological values; scientific and educational values; archaeological, cultural, and historical values; recreational and commercial values; rarity and abundance; and visual quality (see Figure C1). Many of these criteria are interrelated and dependent on each other. For example, a dimensionally large swallet would provide a good hydrologic connection to the subsurface, as well as strong visual appeal.

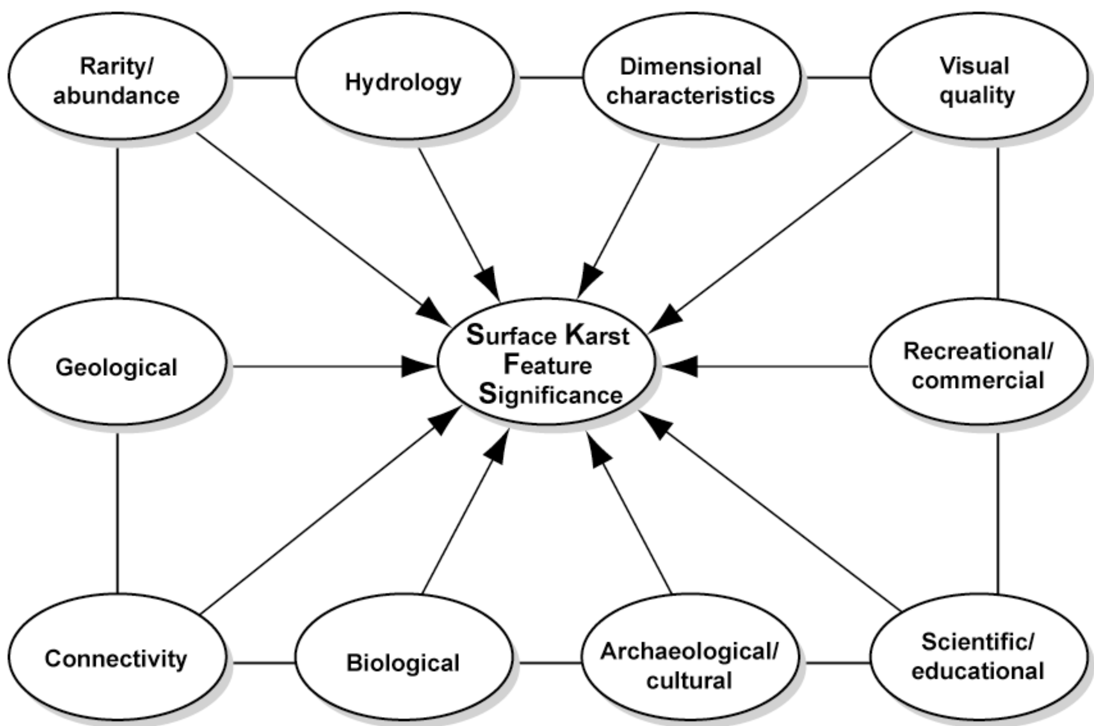


Figure C1. **Characteristics and values contributing to surface karst feature significance.**

Significance Criteria

Dimensional Characteristics

The dimensional characteristics of surface karst features are the length, width, and depth measurements commonly taken during a karst field assessment. As a general rule, the greater the dimensions, the greater the significance; however, this criterion can be strongly tempered by rarity. For example, a 20 m diameter by 15 m deep sinkhole that is common in one location would likely not be as significant as the same-sized sinkhole that is rare in another location. (Note: Calculating the relative volumes between sinkholes of different shapes and dimensions can be an effective way of comparing them; see Figure D4 in Appendix D). Table C2 indicates some of the dimensional characteristics to consider for various types of surface karst features.

Connectivity

The degree of connectivity or openness between a surface karst feature and other surface karst features or the subsurface contributes to the significance of the feature. This connectivity can be through air-filled or water-filled pathways. The presence of water flow, either disappearing or emerging, is an indication of the connectivity within the system. Air flow can be identified by obvious “drafting” in or out of a surface opening; however, in many cases, an air-filled connection is difficult to confirm, especially for small cavities. As a general rule, the greater the connectivity between a surface karst feature and the rest of the karst system, the greater the significance of the feature.

Hydrology

The size of karst lakes and ponds is the principal factor in determining their significance; in general, the larger they are, the more significant they are. Determining the significance of swallets and springs is somewhat more complex. The size of the catchment area for a sinking stream needs to be considered when determining the significance of a swallet. Swallets fed by intermittent or ephemeral sinking streams may be less significant than those fed by permanent sinking streams. Swallets fed by permanent sinking streams with relatively large catchments (e.g., greater than 100 ha) are generally most significant. Springs known to contribute to productive surface streams (i.e., rising streams) or domestic water supplies are significant.

Geological Value

The host bedrock for surface karst features can have a bearing on significance. For example, if a surface karst feature occurs in a bedrock unit or type that is uncommon or rare, it is likely to be significant. Alternatively, the presence of a surface karst feature within a bedrock unit that does not commonly contain karst features may also be significant.

Biological Value

The evaluation of biological values primarily considers the presence of fish in karst waters, and unique or unusual karst-specific flora and fauna and/or their associated habitats. Any fish found in karst waters (lakes, ponds, streams) would increase the significance of the feature. In many cases, large surface karst features (e.g., a large sinkhole) are likely to be suitable habitats for karst-specific flora and fauna. A specialist may be required to identify the specific species of karst flora or fauna; however, an experienced karst field worker should be able to determine the presence of unusual biota or habitats. Section 4.3.12 details some of the likely habitats suitable for karst-specific flora and fauna, and cites available resources for assistance in identifying or confirming species. Confirmation of karst-specific flora or fauna associated with a surface karst feature would increase its significance.

Scientific and Educational Values

Scientific and educational values associated with surface karst features are broad in scope and relatively complex to evaluate. Large surface karst features and those with connections to the subsurface can provide important scientific and educational opportunities in the fields of geology, biology, paleontology, climate change, and landform evolution. Obvious signs of scientific or educational values would increase the significance of a surface karst feature.

Archaeological, Cultural, and Historical Values

Complete evaluation for archaeological, cultural, or historical values associated with surface karst features requires specialized knowledge and expertise, and may include archival research and/or archaeological investigation. It may also include consultation with local First Nations groups and the B.C. Heritage Conservation Branch. Karst field workers should be aware of the likely conditions where these values might occur (shoreline caves, rock shelters, springs, prominent cave entrances, etc.). Evidence of past human use of surface karst features (e.g., wall paintings or fire pits) is an obvious indicator of archaeological value, and would lead to a higher significance rating.

Recreational and Commercial Values

The determination of recreational values for caves requires a separate evaluation, as detailed in the *Cave/Karst Management Handbook for the Vancouver Region* (B.C. Ministry of Forests 1994). However, an experienced karst field worker should be able to determine the potential recreational value for surface karst features based on attributes such as attractiveness, access, interest value, uniqueness, hazard potential, etc. Commercial values that could be considered include commercial surface karst viewing and caving opportunities, or the potential of a spring for commercial mineral water production. Surface karst features with recreational or commercial potential would receive a higher rating for significance.

Rarity and Abundance

The apparent rarity or abundance of a surface karst feature can greatly influence its relative significance. Rarity and abundance can be considered at a variety of scales from local, regional, and provincial to national and international. They can also be considered with respect to other values (e.g., geological, biological, scientific). For example, the presence of a surface karst feature within a karst ecosystem that is poorly represented elsewhere would increase its significance. In general, rare surface karst features would be considered more significant than abundant ones.

Visual Quality

The visual quality of surface karst features has the potential to contribute to both recreational and commercial appeal. The association of a surface karst feature with flowing water, particularly within attractive natural settings (e.g., temperate rain forest), can increase the significance of the feature.

Procedure for Determining Significance

The procedure for determining the significance of a surface karst feature is a qualitative exercise using the matrix table in Table C1. The decision to apply the significance procedure to a particular surface karst feature is primarily based on the experience of the field worker and the guidelines provided in Table C2.

Table C1 contains a list of significance criteria and three categories for significance potential—low, moderate, or high. This table is a valuable tool for comparing or ranking surface karst features against one another—it is not necessarily the final determination of significance. (A significance potential rating is not an absolute measure of the importance or value of a feature.)

In general, if any of the significance criteria are rated high, the feature should be considered potentially significant. If two or more significance criteria are rated moderate and any of the other criteria are unknown, the feature should also be considered potentially significant. In all other situations, the feature is probably not significant. However, the final determination of significance lies with the judgement of the field worker after all features being assessed have been rated for significance potential.

For example, features rated as potentially significant may be reviewed and re-classified by a field worker where the significant ranking is not considered necessary (e.g., mitigative practices would adequately protect the feature without the requirement for a reserve).

Table C1. **Matrix table for evaluating the significance potential of surface karst features**

	Significance Potential					
Significance Criteria	**Low**	**Mod.**	**High**	**Unknown**	**Not Available**	**Comments**
Dimensional Characteristics						
Connectivity						
Hydrology						
Geological						
Biological						
Scientific/Educational						
Archaeological/ Cultural						
Recreational/ Commercial						
Rarity/Abundance						
Visual Quality						

An example field card for determining the significance of surface karst features is provided in Appendix F (Field Card #2).

Table C2. **Guidelines for evaluating significance criteria of selected surface karst features**

Surface karst feature type	Factors to be considered in evaluating significance
Bluffs and canyons	For karst bluffs and canyons, aspect and dimensions are likely to be important, particularly height, which could influence visual quality. A critical factor would be seepage, as this could provide habitat for certain karst flora and fauna.
Hummocks and knolls	Dimensions for these types of positive relief features could be important, particularly if the feature is prominent in the surrounding landscape. However, both scale and rarity would need to be taken into consideration. Visual quality could have an influence.
Sinkholes	The larger the dimensions of a sinkhole, the greater the likelihood of significance; however, this needs to be tempered with rarity. A large (e.g., >20 m diameter) sinkhole could also have its own microclimate, resulting in habitat for unique or unusual karst flora. The openness of a sinkhole at its base would be another important consideration.
Grikes and epikarst zones	The areal and depth dimensions of grikes or epikarst zones are an important consideration for significance. Deep (e.g., >4 m) and/or open-bottomed features could also influence the connectivity to the subsurface and provide habitat for karst flora and fauna.
Swallets and springs	For the most part, dimensionally large swallets, and springs with permanent flow, are likely to be significant. However, smaller swallets and springs could also be significant, as they are evidence for connectivity within the karst system. In many cases, springs and swallets have their own microclimate, providing potential habitat for karst flora and fauna.
Cave entrances and rock shelters	Dimensionally large cave entrances and rock shelters are likely to be significant as they could potentially provide habitat for karst flora and fauna. The likelihood for other values (e.g., archaeological, cultural) is also likely to be greater. However, small cave entrances should not necessarily be considered non-significant, as they can lead to large cave systems.

Appendix D. Classification of surface karst features

Surface karst features are those features of the karst landscape that can be viewed by an observer on the ground up to the threshold of daylight in subsurface openings, including cave entrances. Subsurface karst features are those that are beyond the threshold of daylight.

Surface karst features can be subdivided into the following broad categories:

- insurgences;
- karst springs—resurgences and exsurgences;
- linear features; and
- intersection features.

Insurgences

Insurgences are features that introduce surface water to the subsurface karst environment. The term is independent of size and volume, and describes no specific morphological feature. Insurgences can be characterized as being hydrologically perennial or intermittent based on the hydrological process that takes place. The morphology of an insurgence depends on the structure and lithology of the soluble bedrock present, the local relief, and the volume of water sinking underground.

Confluent insurgences or swallets

A *confluent insurgence* or *swallet* is a type of insurgence with a concentrated water flow, and implies existence of a subsurface conduit. The surface water enters the subsurface after it has been concentrated into identifiable streams. The water will usually sink at separate locations that can be seen and measured as point inputs. Swallet formation is dependent on the presence of impervious rock formations or thick overburden, which provides a surface on which meteoric water can collect as surface streams. For inventory purposes, a swallet may also refer to a concentrated water loss in a streambed even though there is no marked depression. A swallet refers to the site of the water loss, not the stream that leads to it.

In many cases, the growth and evolution of a subsurface conduit system results in the abandonment of some swallets in favour of new upstream swallets called progressive swallets. The adjective “abandoned” is applied to describe the older inactive insurgence. Swallets that are utilized only when upstream insurgences cannot handle peak water flows are termed overflow swallets.

Swallets frequently occur in clusters or complexes associated with the course of pre-existing subsurface conduits. This is because the underlying conduits serve as a drain for surface water. Swallets can also cluster if one of the insurgences cannot accommodate peak flows, resulting in the use of overflow swallets. In mantled karst units, swallets tend to cluster where the soluble rock is exposed, because this is where surface water flow is more likely to sink.

Diffuse insurgences

A *diffuse insurgence* is where surface water enters the soluble bedrock as a series of small, dispersed inputs by percolation (through overburden, if it exists) into small openings in the bedrock. In this case, water flow is not related to a definable surface stream. The infiltration routes are small openings, usually joints or fractures in the bedrock. The concentration of water flow takes place in the subsurface environment, not in the surface environment (as with confluent insurgences or swallets).

Karst Springs

Karst springs are features that discharge water from the subsurface environment, and can be classified as either resurgences or exsurgences.

Resurgences

Resurgences are where water collected at swallets is transmitted by solution conduits and discharged to the surface environment to form a surface stream (i.e., *rising stream*). These features are the downstream end members of karst networks. The actual surface opening may be totally or partially obstructed by collapse or unconsolidated surficial materials, including colluvium. The observable openings can be perennially or intermittently submerged (i.e., flooded). *Overflow springs* are resurgences that are used when the normal spring is incapable of handling the volume of water transmitted to it. As with insurgences, the maturation of a karst unit may result in the abandonment of resurgences in favour of newer ones. In such a case, the old discharge point is classified as an *abandoned karst spring*.

Exsurgences

Exsurgences are the downstream reappearance of local infiltration (i.e., a diffuse insurgence) of surface water. The term is applied if the origin of the discharge water cannot be confirmed to be predominantly a confluent insurgence or a swallet.

Linear Features

The majority of linear features can be divided into two broad types: fluviokarst and merokarst. *Fluviokarst* features are found in karst landscapes in which there is evidence of past or present fluvial activity. *Merokarst* features are found in areas of imperfect karst topography, where surface drainage and dry valleys are found in addition to some karstic features.

Examples of fluviokarst features:

A *sinking stream* is a small stream that disappears underground at a karst insurgence, usually a swallet.

A *losing stream* is a surface watercourse that gradually loses water along its bed, particularly when unconsolidated sediments form the bed.

A *gaining stream* is a surface stream in karst that gradually gains water along its bed.

An *interrupted stream* is one that repeatedly disappears and resurges.

A *rising stream* is the surface course of an emergent underground stream. A karst river is a more important watercourse that originates from a karst spring.

Examples of merokarst features:

A *dry drainage segment* is the portion of an elongate natural karst depression between intersecting depressions or other terminations.

A *karst canyon* is a deep and narrow gorge or ravine, with vertical or subvertical slopes underlain by soluble rock containing a perennial or intermittent stream. This feature in karst is frequently formed by a river originating from impervious rock outside the karst unit. A *slot canyon* is a soluble bedrock canyon with vertical or overhanging walls and a depth-to-width ratio greater than 3:1.

A *swale* is a slightly elongate natural depression in generally level karst terrain, without a permanent watercourse. It is generally shallower than a draw or ravine. The gradient of the sideslopes is generally less than 20%.

A *draw* or *ravine* is an elongate depression in sloping karst terrain, without a permanent watercourse. The gradient of the sideslopes is generally between 20 and 40%.

A *dry gully* has steeper sides than a draw and is usually found in steeper karst terrain. The gradient of the sideslopes is generally greater than 40%.

A *karst valley* is an elongate solution valley with inclined sides. The valley may or may not contain a stream. A *blind karst valley* is a valley that usually terminates at a swallet. It may have a perennial or intermittent stream that sinks at its lower end, or it may be a dry valley. A *half-blind karst valley* is a blind valley that overflows to a surface stream when the flow of water entering the blind valley exceeds the maximum capacity that the downstream swallet can accept.

Surface karst features that form abrupt slopes on one side, such as escarpments and cliffs, are termed linear *karst declivities*. For inventory purposes, these features must have an altitudinal difference of at least 2 m, and have a length greater than 10 m.

Examples of linear karst declivities:

A *karst steephead* is the head of a valley in a karst unit, generally short and restricted at the headward end by an escarpment. It is commonly associated with a karst spring.

A *solution scarp* is a long, cliff-like ridge of soluble bedrock, a steep slope, or drop of a precipitous line of cliffs, terminating high land abruptly. It can be formed by the more active solution of the lower area or by corrosional undercutting of the base.

A *cliff* is a high, steep face of soluble bedrock.

A *cuesta* is a long, low ridge with a relatively steep face, or escarpment on one side and a long, gentle slope on the other.

Intersection Features

Intersection features are the connections that exist between the surface and subsurface karst environments, and do not relate to an appreciable water insurgence to, or emergence from, a known subsurface conduit system. Weathering phenomena other than solution process can contribute to their formation. After initial formation, an intersection feature may be transformed into an insurgence (or resurgence) by the capture (or release) of water from nearby areas.

Negative relief point features

Negative relief point features are the most common type of intersection features. These may appear to be solutional in origin, but their final surface expression may be due to other weathering processes.

Examples of negative relief point features:

A *solution pan* is a shallow dish-shaped depression in soluble bedrock, with a flat bottom and steep, occasionally overhanging sides. The diameter of these features ranges from several decimetres to several metres. For inventory purposes, a solution pan has a depth greater than 20 cm and a diameter ranging from 20 cm to 2 m maximum. The width-to-depth ratio is two, minimum.

A *sinkhole* is a topographically closed karst depression, wider at the rim than it is deep. It is commonly of a circular or elliptical shape with a flat or funnel-shaped bottom. A sinkhole can have sinuous interior contours, but no angular contours. For inventory purposes, a sinkhole must have a deepest point at least 2 m below the surrounding landscape, and have a width greater than 2 m. A *shakehole* is a variant of a sinkhole, and is formed by solution, subsidence, or compaction in loose drift or alluvium overlying beds of limestone. An *uvala* is a large karst depression with a rugged bottom, often formed by coalescent sinkholes. It may contain other smaller nested features. For example, the host uvala may contain a karst stream that eventually sinks at a swallet.

A *shaft* is a deep solution hole, generally circular in outline, having vertical or nearly vertical walls. It tends toward a cylindrical shape, and is without a passage or chamber leading from it. A shaft is a vertical cavity with approximately equal horizontal dimensions and a much larger vertical dimension. Also referred to as a pothole, it is wider than a chimney.

A *karst pond* is a karst depression enclosing a standing water body. For inventory purposes, it has a diameter less than 10 m and a depth less than 1 m. A karst depression enclosing a standing water body with a diameter greater than 10 m, and with a depth greater than 1 m, is termed a *karst lake*. A *karst fen* is a marshy depression developed in sinkhole terrain. A *karst window* is a depression revealing part of an underground stream flowing across its floor (also an unroofed part of a cave).

A *natural well* is a large sinkhole with subvertical walls, containing a water body that intersects the phreatic zone.

Examples of vertical intersection features, subject to certain size limits, used for estimating epikarst development (see Section 4.3.6):

A *karst joint* is a fracture in soluble bedrock, generally more or less vertical or transverse to bedding, along which no appreciable movement has occurred. For inventory purposes, joints must have a width less than 20 cm, and an elongation ratio of 1.5, maximum. They are generally smaller than a fissure, but larger than a rock fracture that is not enlarged by solutional weathering. The depth-to-width ratio is two, minimum. A *karst fissure* is an open crack in bedrock that is only slightly enlarged by solution weathering. For inventory purposes, fissures must have a width of between 10 and 20 cm, and an elongation ratio of 1.5, maximum. They are generally larger than a joint, but smaller than a grike. The depth-to-width ratio is two, minimum.

A *grike* is a deep, narrow, vertical or steeply inclined, rectilinear slot with almost parallel sides. Grikes are usually found in a bedrock outcrop and are caused by solution along a joint. For inventory purposes, they have a depth greater than 20 cm and a diameter ranging from 20 cm to 2 m. The elongation ratio is two, minimum.

For inventory purposes, a *karst cleft* is a rectilinear hole with the form of a large fissure or grike, between two abrupt walls at least 20 cm apart. The maximum width is less than 2 m. The elongation ratio is two, minimum. The depth-to-width ratio is also two, minimum.

A *solution* tube is a rounded solution hole or small tunnel of any orientation. The vertical forms, called chimneys, are generally larger and more rounded than a grike. For inventory purposes, a tube is a vertical or subvertical cylindrical hole with a diameter of greater than 50 cm but less than 2 m, extending from the surface to a depth of 2 m or more. The elongation ratio is two, minimum. The depth-to-width ratio is also two, minimum. A *pipe* is a vertical or subvertical cylindrical hole with a diameter of less than 50 cm, extending from the surface to a depth of 1 m or more. For inventory purposes, the elongation ratio is 1.5, maximum. Pipes are often filled with soil and unconsolidated sediments and/or breccia. The depth-to-width ratio is two, minimum. A *chimney* is a solution hole, generally circular in outline, having a marked degree of sinuosity. The feature is without a passage or chamber leading from it. It has approximately equal horizontal dimensions at the surface opening and a much larger vertical dimension. It is generally smaller in cross-sectional area than a shaft.

Lateral intersection features

Lateral intersection features frequently occur along retreating cliffs, and where steep slopes uncover pre-existing solution conduits.

Examples of lateral intersection features:

A *natural arch* is a small natural rock bridge that does not span a karst valley.

A *natural bridge* is a large natural rock bridge that crosses a karst valley.

A *natural tunnel* is a horizontal or sub-horizontal cavity open at both ends, generally fairly straight in direction, and fairly uniform in cross-section. No part of the feature is beyond daylight.

Positive relief features

A positive relief feature is a residual landform that rises above the surrounding karst landscape.

Examples of positive relief features:

A convex *outcrop* is a small exposure of soluble bedrock projecting through overlying layers of detritus and soil.

A *hum* is a small residual hill of soluble rock standing above a recently eroded soluble rock surface. For inventory purposes, a karst hum must rise at least 2 m above the surrounding landscape and have a basal area of not less than 0.01 ha, but less than 0.1 ha. A *hummock* is a knoll or small elevation, larger than a hum. For inventory purposes, it has a basal area greater than 0.1 ha.

A *karst ridge* is a long, narrow hill of soluble bedrock. For inventory purposes, a karst ridge is a positive landform rising at least 2 m above the surrounding landscape, is more than 10 m long (as measured along the longitudinal axis), and has a minimum 4:1 length-to-width ratio.

Cave entrances

Surface openings large enough to admit a human being, connecting to interior cavities that contain a zone of complete darkness, are *cave entrances*. A cave entrance is part of the cave or cave system and may be nested within one or more other surface karst features. For example, a cave entrance may be located within a sinkhole and swallet—these are also examples of nested or compound karst features.

A cursory inspection of the cave entrance can be made to establish if penetrable interior cavities exist beyond the threshold of daylight. If a subsurface inspection is deferred for any reason, the feature is tentatively classified as a *possible cave entrance*. Cave entrances can vary widely with scale and structure. They are categorized according to whether they are dimensionally *large* or *small*, or have *vertical* or *horizontal* aspects. Large entrances have a cross-sectional area greater than 10 m^2. Small cave entrances have a cross-sectional area less than 10 m^2 but are penetrable (without removing obstructions or excavation).

For inventory purposes, the cross-sectional area of a horizontal or sub-horizontal cave entrance is visually estimated at the vertical plane formed by the most probable *dripline*. The dripline is a line on the ground at a cave entrance formed by drips from the rock above. The cross-sectional area of a vertical or subvertical entrance (e.g., a shaft or grike) is visually measured at the horizontal plane formed by the highest closed contour.

Miscellaneous surface karst features

A *rock shelter* is a solution hollow with a more or less level floor reaching only a short way into a hillside or under a fallen block. No enterable part of the feature is beyond the reach of daylight.

Figure D1 provides mapping elements and symbols, and measurement standards for surface karst features.

Feature Types			Limits	Symbols	Mapping Elements	Measurement Standards		
Insurgences e.g., Swallets	Aspect: Horizontal and subhorizontal	Mean Diameter	≤10 m		A single point in the centrepoint of the dripline	The cross-sectional area (A) is calculated as per Figure D2	The flow rate (Q) is the estimated discharge in litres per second, at the surface opening	The submergence (S) is the percentage of the cross-sectional area occupied by water flow
			>10 m		The top of the vertical plane formed by the surface opening is plotted as a curvilinear element			
	Aspect: Vertical and subvertical	Mean Diameter	≤10 m		A single point in the centrepoint of the plane, formed by the bedrock surface opening	The cross-sectional area (A) is calculated as per Figure D3		
			>10 m		The plane formed by the surface opening is plotted as a polygon			
Karst springs	Aspect: Horizontal and subhorizontal	Mean Diameter	≤10 m		A single point in the centrepoint of the dripline	The cross-sectional area (A) is calculated as per Figure D2	The flow rate (Q) is the estimated discharge in titres per second, at the surface opening	The submergence (S) is the percentage of the cross-sectional area occupied by water flow
			>10 m		The top of the vertical plane formed by the surface opening is plotted as a curvilinear element			
	Aspect: Vertical and subvertical	Mean Diameter	≤10 m		A single point in the centrepoint of the plane, formed by the bedrock surface opening	The cross-sectional area (A) is calculated as per Figure D3		
			>10 m		The plane formed by the surface opening is plotted as a polygon			
Diffuse resurgence area		Area	≤0.01 ha		Plotted as a single point			
			>0.01 ha		Plotted as a polygon enclosing the insurgence			
Linear karst features e.g., Slot canyons	Axial length		≤10 m		Not normally found or applicable	The length of the feature (L) is the combined length of all segments	The width of the feature (W) is the mean width perpendicular to the axis of the feature	The gradient is the general slope, or rate of vertical drop per unit of length of a feature segment
			>10 m		Plotted as a curvilinear element along the longitudinal axis of the feature			

Figure D1. **Mapping elements and symbols, and measurement standards for surface karst features.**

Feature Types		Limits	Symbols	Mapping Elements		Measurement Standards	
Linear declivities e.g., Cliffs	Altitudinal Difference	2 m ≤ h ≤ 10 m		Plotted as a single point in the centrepoint of the landform		The mean diameter of the feature (D) is the average length of two right angle lines crossing the maximum length (L) and width (W) relative to the area of exposed bedrock	The height of the feature (H) is the maximum height of the feature, relative to the mean elevation of the base of the feature
		>10 m		The dripline is used and plotted as a curvilinear element			
Negative relief point features e.g., Sinkholes	Mean Diameter	≤10 m		A single point in the centrepoint of the plane, formed by the bedrock surface opening		The cross-sectional area (A) is calculated as per Figure D2	The volume (V) is calculated as per Figure D4
		>10 m		The plane formed by the surface opening is plotted as a polygon			
Cluster of small features	Area	≤0.01 ha		Plotted as a single point			
		>0.01 ha		Plotted as a polygon enclosing the insurgences			
Lateral intersection features e.g., Natural arches and bridges	Axial length	≤10 m		Plotted as a single point in the integrated centrepoint of the span		The span length (L) is the axial length of rock suspended over the enclosed air space	The span width (W) is the width of the rock at its centrepoint
		>10 m		The span is plotted as a line			
Natural tunnels		≤10 m		Plotted as a single point		The length of the tunnel (L) is the maximum distance between the dripline centrepoints of the surface openings	
		>10 m		Tunnel openings are plotted as separate points			

Figure D1. **Continued.**

Feature Types				Limits	Symbols	Mapping Elements		Measurement Standards	
Positive relief point features e.g., Hums	Mean Diameter			≤10 m		Plotted as a single point in the integrated centrepoint of the landform		The mean diameter of the feature (D) is the average length of two right angle lines crossing the maximum length (L) and width (W) relative to the area of exposed bedrock	The height of the feature (H) is the maximum height of the feature, relative to the mean elevation of the base of the feature
				>10 m		Plotted as a polygon			
Cave entrances	Aspect	Horizontal and subhorizontal	Mean Cross-sectional Area	≤10 m^2	∩	A single point in the centrepoint of the dripline		The cross-sectional area (A) is calculated as per Figure D2	
				>10 m^2	∩	The dripline is used and plotted as a curvilinear element			
		Vertical and subvertical		≤10 m^2	∨	Plotted as a single point in the centrepoint of the plane formed by the opening		The cross-sectional area (A) is calculated as per Figure D3	
				>10 m^2	∨	The plane formed by the surface opening is plotted as a polygon			
Rock shelters	Mean Cross-sectional Area			≤10 m^2	⊂	A single point in the centrepoint of the dripline		The cross-sectional area (A) is calculated as per Figure D2	
				>10 m^2	⊂	The dripline is used and plotted as a curvilinear element			

Figure D1. **Continued.**

Circular entrance of radius *r*

$$A = \pi r^2$$

Elliptical entrance of height *h* and width *w*

$$A = \pi hw$$

Parabolic entrance of height *h* and base *b*

$$A = \frac{2}{3} hb$$

Rectangular entrance of height *h* and width *w*

$$A = hw$$

Parallelogram-shaped entrance of height *h* and base *b*

$$A = bh$$

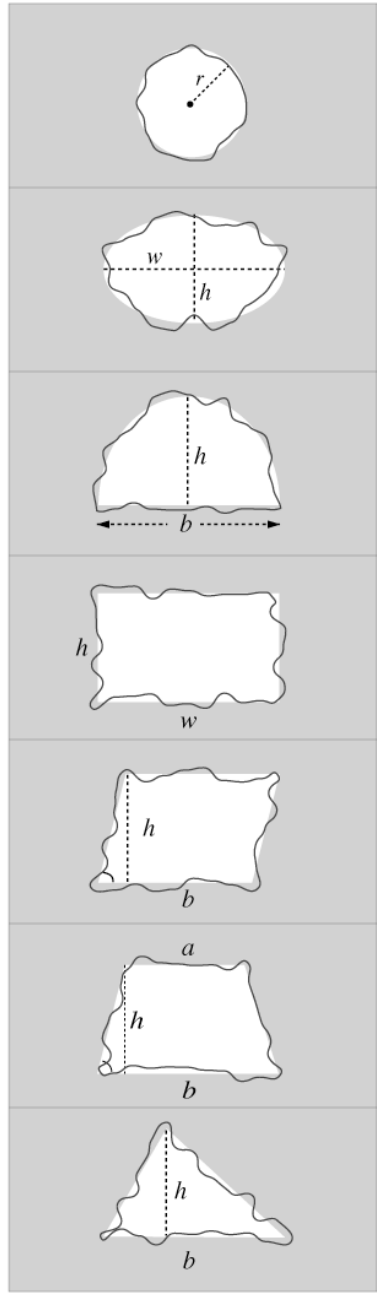
Trapezoidal entrance of height *h* and parallel sides *a* and *b*

$$A = \frac{1}{2}h(a + b)$$

Triangular entrance of height *h* and base *b*

$$A = \frac{1}{2} bh$$

Profile view



Note: For inventory purposes, the cross-sectional area of a horizontal or sub-horizontal cave entrance is visually estimated at the vertical plane formed by the most probable dripline. The dripline is a line on the ground at a cave entrance formed by drips from the rock above.

Figure D2. **Cross-sectional area of cave entrances with horizontal or sub-horizontal aspect.**

Circular entrance of radius r

$$A = \pi r^2$$

Elliptical entrance of length l and width w

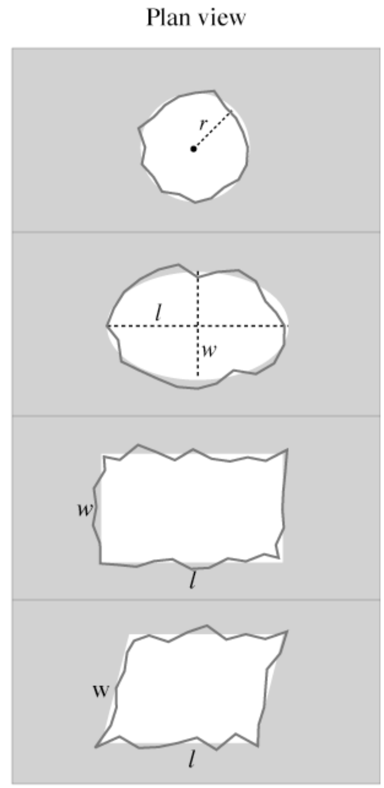
$$A = \pi\ lw$$

Rectangular entrance of length l and width w

$$A = lw$$

Parallelogram-shaped entrance of length l and width w

$$A = lw$$



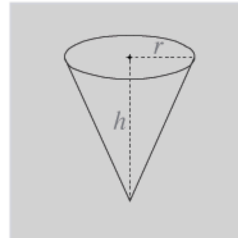
Note: The cross-sectional area of a vertical or subvertical entrance (e.g., a shaft or grike) is visually measured at the horizontal plane formed by the highest closed contour.

Figure D3. **Cross-sectional area of cave entrances with vertical or sub-vertical aspect.**

Right circular funnel of radius r and depth h

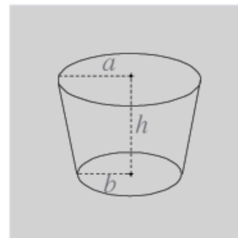
$$\text{Volume} = 1/3Ah$$

$$\text{where } A = \pi r^2$$



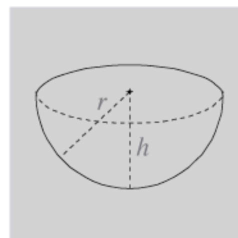
Frustrum of right circular funnel of radii a, b and depth h

$$\text{Volume} = 1/3\pi h(a^2 + ab + b^2)$$



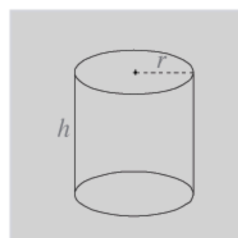
Spherical bowl of radius r and depth h

$$\text{Volume} = 1/3\pi h^2(3r\text{-}h)$$



Right circular cylinder of radius r and depth h

$$\text{Volume} = 2\pi rh$$



Circular cylinder of radius r and slant height L

$$\text{Volume} = \pi r^2 h = \pi r^2 L\sin\theta$$

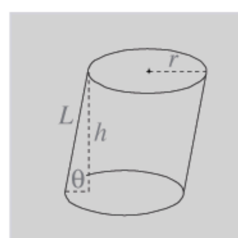


Figure D4. **Geometry and volume of depression features.**

Appendix E. Searching for cave entrances in old-growth forests: an overview of ground-based methods employed in north and central Vancouver Island, British Columbia

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ABSTRACT

Ground-based methods have been used since 1982 by forest licensees and inventory contractors to search for cave entrances in the remnant old-growth forests of North and Central Vancouver Island. Methods have ranged from a low-intensity preliminary reconnaissance to a high-intensity saturation search. Moderately intensive sampling methods, such as the grid pattern (i.e., strip) search and judgemental search, will be evaluated for effectiveness and cost efficiency.

INTRODUCTION

The remnant primary old-growth forests of Canada's West Coast are globally rare temperate rainforests.

The forests atop north and central Vancouver Island's karst are complex ecosystems. Very old and large coniferous trees form a dense canopy, which, combined with frequent fog and precipitation, make aerial detection of all but the largest cave entrances difficult. Consequently, resource managers most commonly employ ground-based search methods to inventory cave entrances in old-growth forest stands.

Methods that have been successfully used by the B.C. Ministry of Forests and coastal timber licensees include:

a) Reconnaissance (or walkabout)
b) Strip (or transect)
c) Judgemental (or feature-oriented)
d) Total (or saturation)

The search strategies have occasionally been combined and stratified, or at least modified to better suit field conditions. The most appropriate field method depends on the specific objectives of the cave entrance inventory and the nature of the forest environment.

The reconnaissance is normally the least intensive ground search method, while the strip and judgemental, based on systematic sub-sampling, are moderately intensive. Searching can also be very intensive, such as with total surveys (i.e., as would occur in a tight grid network).

All surface inventories usually begin with a desktop review of aerial photography, geological mapping, and records of known feature occurrences. These front-end tasks, or "filters," constitute important elements of the stratified inventory.[1]

Background to specific requirement

The specific requirement to locate cave entrances was introduced in the *Cave/Karst Management Handbook for the Vancouver Forest Region*[2] (June 1994) hereinafter referred to as the "Handbook"). Retained in the July 1994 version, the current guideline[3] reads as follows:

"When a proposed development boundary lies within a karst formation, as identified by the L5 feature in the recreation inventory, a *systematic surface inventory* to locate *cave entrances* must be undertaken within this area as well as for the karst formation surrounding the development boundary."

Accordingly, the primary objective of all ground searches is to locate cave entrances to meet this administrative requirement. The information collected as a result is used for updating recreation inventories, the completion of which is required under section 28(d)(i) of the *Forest Act*.

Surface surveys can also lead into a complete multidisciplinary cave/karst inventory and assessment project, which necessitates the subsurface inspection of found caves. Locating "hydrological" features, such as active insurgences and exsurgences, is also an important precursor to the design of dye tracing studies. Found swallets can be used for the introduction of dye, while springs serve to monitor dye travel.[4] The surface inventory information is also used to enable concurrent or subsequent subsurface inspection of caves. In practice, a secondary objective may be to establish other important biophysical site characteristics (soils, wildlife, etc.). (This phase of inventorying is beyond the scope of this paper.)

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[1] Photogrammetry can identify certain biophysical indicators (e.g., large tree canopy gaps and surface lineaments that are sometimes associated with cave entrances). Aerial photography can also reveal karst features in adjoining and analogous cutover areas, from which inferences can sometimes be drawn about the closed-canopy inventory area.

[2] The Handbook guidelines are optional or voluntary practices not currently in the Forest Practices Code (FPC), but the implication is that they are to be used to meet resource management objectives. The handbook was to have been replaced by the FPC Cave Management Guidebook in preparation. Nonetheless, handbook guidelines can be made legally enforceable when they are inserted in plans, prescriptions, and contracts. The MOF Regional Manager requires the interim implementation of the Handbook procedures, including systematic surface inventories, under the authority of a written directive to MOF districts and licensees.

[3] Previously, MOF management guideline and policy statements prescribed only general cave inventories. The current Handbook also states that the "extent and intensity" of the surface inventories must be approved by the MOF District Resource Officer Recreation.

[4] Dye studies are being used with increased frequency by British Columbia resource managers and recreational cavers to enrich the understanding of the hydrogeology of the more sensitive karst units.

METHODS

The objective of the systematic surface inventory is to gather information about the occurrence of cave entrances over the ground sampled, and to occasionally make inferences about adjacent unsampled terrain. Of the three sampling survey methods described below, only the reconnaissance search is not, strictly speaking, a systematic search (i.e., a search type that is not characterized by a system or method).

Reconnaissance search

The reconnaissance is most often used in combination with the judgemental search. The search route usually consists of a transverse line (i.e., a line that crosses from side to side between the boundaries of the inventory area). In addition, it can be used to search along projected road rights-of-way.[5]

This reconnaissance is a type of sampling survey often used as the first field phase of a stratified inventory.

Strip search

With the strip search method,[6] the general grid layout and orientation of search lines are selected based on practical considerations. Thereafter, the individual search lines are mechanically and uniformly spaced at fixed intervals.

Typically, a single person establishes a search centre line with a handheld compass, clinometer, and hip chain, while making the necessary observations within the field of view. Two 3

searchers rove over the ground in a "zigzag" fashion on opposite sides of the centre line. At a minimum, the azimuth and chained distances are recorded for the centre line. Clinometer readings may be taken when traversing sloped terrain.[7]

Depending on the type of karst terrain to be searched, the centre line interval (and the width of the strips) is sometimes varied. Inventories have been conducted at 100-m, 50-m, and 30-m centre line intervals. The visibility and ease of cave entrance recognition under different forest stand conditions may set the optimal balance between these limits. The 90-m width is the most commonly used centre line interval and assumes a mean visible range of 10–15 m. At this interval, the three members of the crew start the search spaced 30 m apart.

The strip method is a technique that is particularly useful when making comparisons between karst zones.

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[5] It is generally accepted that the road building phase of forest development can produce the greatest impacts.

[6] The strip search was first used in 1982 to inventory selected timber harvest units in the Tahsish River drainage of northwestern Vancouver Island.

[7] More accurate centre line surveying can be specified, however. To maintain 1:100 horizontal accuracy, for example, the instruments must be capable of readings in one-degree increments. Distance measurements to the nearest 0.1 m are periodically required by the sponsoring agency or client. Shots average 10–12 m depending on conditions. The survey stations are established in the field and marked. If the search centre lines are accurately surveyed, they can be used to tie in features found.

<u>Judgemental search</u>

The judgemental search is the second type of systematic sampling survey. The method is based on the recognition that surface karst features do not occur in random order.[8]

By analyzing inventory data, it has been possible to identify the association between surface karst features and one or more terrain variables. These correlations have been verified by regression analysis and established for Vancouver Island forest karst ecosystems. For example, there is shown to be a strong positive or direct correlation between the topographic position of swallets and upper limestone contacts. Conversely, a negative (i.e., inverse) correlation exists between steep hillslopes and dolines. There are many such correlations, learned principally through experience.

<u>Total search</u>

Total searches are usually conducted on a regular grid system, with quadrats as small as 20 by 20 m.[9] They are occasionally employed for small development units, and generally yield the most accurate results.

As with all search methods, the nature and location of notable karst surface features, other than cave entrances, must also be described in field notes, to both characterize the karst terrain and to aid in locating the feature again later.

DISCUSSION

This following discussion is a comparative evaluation of the two most commonly employed methods of systematic surface inventorying—strip and judgemental sampling surveys.

<u>Compliance with applicable guidelines</u>

Both search methods generally satisfy the legislative requirement to perform an orderly and methodical surface inventory, as established in the *Handbook*.

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[8] It was first used to survey selected timber cutblocks in the Holberg area of northern Vancouver Island, where inventory areas were interspersed with poorly drained transitional fen-bogs and hydrophilic vegetation. The initially mandated ground search of these areas entailed time-consuming and exhaustive fieldwork. (The poorly drained areas did not show many features!)

[9] Strip searching with narrow transects can also lead to complete ground coverage under certain conditions.

Human Resources:

Number of persons required

The minimum crew size for the transect search is three persons, assuming that the centre line surveyor uses a hip chain as a distance measurement device. A chained traverse requires a second person on the centre line.

The judgemental search method generally requires fewer persons over shorter periods. In theory, one person can perform this type of surface survey, provided that provincial safety and client policy requirements are met.[10]

Required skills

The relatively higher cost of the strip search (see "Estimated cost"), and higher crew complement, can lead to the use of less skilled and inexperienced labour. Although most persons can readily recognize classic cave entrances, difficulties in interpreting the full range of certain karst characteristics associated with unusual or uncommon atmospheric openings can bias the search. These are not inconsequential problems if systematically repeated throughout the inventory unit.

The judgemental search generally requires a higher skill level than that called for in grid or transect searching and this can add to the cost. This eventuates in higher-quality documentary output, however.

Lower turnover can help to ensure consistency between searchers.

Duplication of effort:

This strip method does not efficiently take into account the field knowledge acquired by forest workers who may have already traversed the inventory area, many of whom can reliably recognize cave entrances. The reliability of karst-specific observations made by these workers has steadily improved over recent years. Indeed, their capability can exceed that of sport cavers, who, perhaps because of their location and/or interests, may have been minimally involved in searching for caves in old-growth forest.

Timing and scheduling

The longer duration of the strip search, unless multiple crews are deployed, means that it is potentially subject to more frequent weather-related interruptions and delays (hazardous windstorms, snowfalls, etc.). This becomes an important limiting factor in remote locations where access is by air transport or watercraft.

Efficiency

One of the drawbacks of the strip search arises from the fact that karst surface features (e.g., cave entrances) are not evenly spaced over the entire inventory unit, but are determined by topography and clustered. This can sometimes mean that broad tracts of land are sampled where no significant features are found.

[10] It is permissible for one person to work alone if a means of periodically checking the well being of this individual is instituted pursuant to Section 8.32 ("Men Working Alone") of the B.C. Industrial Health and Safety Regulation. This procedure entails a scheduled check-in by portable VHF radio. In practice, however, a minimum two-person crew is deployed during periods of inclement weather and/or in remote forest development areas. Transceivers are also used in cases where voice communication between workers is not possible.

Such is particularly the case when the nature and/or depth of the regolith may have masked, or almost completely obscured, the surface expressions of the karst formation.

Cave entrances are frequently controlled or at least influenced by topography. For example, in hillslope areas, swallet-type cave entrances are most likely found where surface streams intersect the upper limestone contact. As ellipsoid features, with a tendency toward downslope orientation, these swallets are not as quickly located if the multiple strips are run across the hillslope, and below the contact zone.

With the judgemental search, the field personnel can usually be deployed more efficiently. For example, each person can follow separate pre-designated search routes. As well, persons can handle separate field tasks in the same zone concurrently.

Rate of progression

A limiting factor for the strip search can be the sponsoring agency's or client's requirement to accurately survey the centre line.[11] As the centre line surveyor is generally the slowest person in the three-person crew, lateral searchers must accommodate this to maintain their position relative to the centre line. One of the advantages of the strip search is that the surveyed centre lines are available for accurate entrance tie-ins.

In addition, the field tasks are generally more onerous for one lateral searcher than for the other. This is particularly true when multiple karst surface features are found. Hence, one lateral searcher must periodically wait for the other. Although pacing distances is much quicker and easier, especially for independent searchers or in shrubby or dense forests, it is less accurate than chaining. Transect distances and cave entrances along transects are measured by using metric hip chains.

Obstacle areas:

Problems can arise when a strip is constrained to a straight-line course over obstacles (e.g., short steep bluffs, perched bogs, windfall areas). The rate of progression is negatively affected when such difficult zones are traversed and the lateral searchers are deflected off their search route axes. Furthermore, these areas frequently exhibit lower karst cave entrance potential, except at the periphery.

Of the two sampling survey methods, the judgemental search better lends itself to where there are extensive patches of dense undergrowth or windthrow on uniform terrain. These occurrences are rarely associated with cave entrances. While the strip search centre line must generally follow a compass course through these patches, the judgemental searcher is not bound to a straight-line compass traverse. The latter searcher can circumvent these osbtacles whenever necessary.

Sampling bias

[11] Resource managers have occasionally required surveying search routes to 1:100 accuracy. This involves the use of a hand-held compass and clinometer.

The probability of finding a cave entrance using the strip method largely depends on its size (assuming symmetry in all other respects). Entrances must be large enough to see at a reasonable viewing distance. (Note: A dry [i.e., noiseless] pit measuring 0.25 m across can easily be missed at a distance of 10 m with moderate understorey.) Thus, large entrances are more likely to be found than small ones.

Similarly, sampling biases can occur when an inexperienced observer underestimates the potential of karst land units with few surface karst expressions. How thoroughly the ground is searched will also depend on the care exhibited by individuals—the less perceptive searchers will tend to miss features. Failure to locate a cave entrance could result from this bias. In addition, individual bias can be introduced by the differing physical stamina of lateral searchers. For example, more enthusiastic and energetic lateral searchers will tend to cover more ground (i.e., the overall amplitude of the "zigzags" tends to be greater). If lateral searchers are imperfectly matched, then the overall rate of progression is reduced to that of the slowest person.

The judgemental method is not as biased toward large cave entrances, as all features along the access route and the target zone are more likely to be inspected. Size distributions of entrances obtained by this method cannot be compared directly to results provided by the other methods.

Cave entrances of all types may be more easily missed when wide centre line intervals and strips are used. Ten-metre wide strips can increase the number of small entrances found. However, if larger entrances are the primary object of this surface survey (e.g., because they are more likely to be penetrable), then narrower grids may not be advantageous.

A particular potential bias toward finding large cave entrances exists because the centre line searcher more readily sees them. Entrances at the limit of the searcher's visibility range, but still within the middle strip, will be missed more often than in the lateral strips. This is due to the fact that the centre line person does not normally break the chain to inspect collateral features or to "zigzag."

Another potential bias arises between the lateral searchers themselves. The probability of finding an entrance in a homogeneous land unit is roughly proportional to the amplitude and length of the search path wave or "zigzag" (i.e., the distance travelled). Assuming the same visibility range, the probability is greater if the searcher increases the amplitude of the "zigzag." Wider strips should result in finding more entrances than narrow or line transects, and the effect would be greatest for small entrances.

<u>Coverage</u>

If a 90-m interval search line is selected and a 15-m lateral visibility range is assumed for equidistant searchers, then a 100% sample is theoretically possible with the strip method. In practice, however, the actual sample size is highly variable when the terrain is broken and where poor visibility conditions prevail. Inventory contractors have reported that a 50–80% sample is possible under *optimal* conditions.

<u>Rights-of-way</u>

Unless the projected rights-of-way can be used as reference or base lines, the non-rectilinear layout means they can be searched only by the intersecting fixed search lines, and the random intersections of lateral search routes. These intersections can occur at perpendicular and oblique angles on hill slopes.

This judgemental method can be efficiently employed to search along projected road rights-of-way. The method allows for efficient linear searching of projected rights-of-way, particularly those that traverse across hill slopes. One person can usually search the standard road width from the centre line, assuming a visibility range of 15 m.

Concurrent tasks

For strip searches, concurrent subsurface inspection of complex and/or technically difficult caves necessitates lengthier surface carries. The requisite heavy loads of harnesses, rope, and hardware are transported over search paths or cached at intervals. This reduces the overall rate of progression. Judgemental searchers tend to carry the gear for preliminary subsurface inspections of caves at all times.

Other karst surface features and terrain characteristics

Strip searching for more common karst surface features (e.g., dolines) allows the searcher to make more precise determinations about karstification (e.g., index of subsurface karstification[12]). However, in the case of narrow transects there is no guarantee that the unsampled features that lie outside the transect are as numerous as inside the transect.

In the judgemental search, the knowledgeable searcher can design traverse routes to make some inference about the karstification of the unsampled portion of the inventory area. However, the level of experience required is higher.

[12] The karstification index is the number, expressed in square kilometres of apertures of karstic conduits (swallets, dolines, exsurgences, etc.), that can be detected on the surface of the karst. The index of subsurface karstification is the sum of discrete karst surface features sampled divided by the total area of the strip transects.

Estimated cost

The average cost of strip searching varies according to centre line interval—for lines established at 90-m intervals, and to 1:100 survey accuracy, it ranges from $200 to $250 per hectare. This cost estimate includes the associated field tasks (e.g., entrance identification).

The cost range for judgemental searching is $50–80 per hectare. In judgemental sampling, a search area is divided into zones of known higher probability, and traverses are selected by an experienced contractor for the purpose of sampling these zones. This approach has several advantages. If search routes are carefully selected, the results will be obtained in less time than required for a systematic grid or transect search. Aside from the temporal efficiency, the overall cost of the search will be much more favourable.

CONCLUSIONS

For most inventories in large forest tracts, it has not been economically feasible to search 100% of an inventory area. The number of field workers required and the manner in which they can be deployed greatly influence the cost of a survey. Aside from cost, the time required to complete more intensive searches is also a major consideration.

Larger units may require many repeat visits and take several years to complete. Administrative timelines and ground access problems (e.g., inclement weather) are often important constraining factors.

The prevailing compromise is to use a moderately intensive method and to randomly exclude many of the smaller features from more detailed fieldwork. Field time is thereby most profitably employed on the cave entrances of primary interest and importance.

Carefully designed sampling surveys have become an accepted method of inventorying for cave entrances in forest development units that cannot be completely searched due to time and cost constraints.

Though the statistics for finding entrances and of projecting the number of unsampled entrances have not been developed for the two systematic sampling methods, strip and judgemental, it is believed that for a given land unit they produce similar results.

The strip search appears to be most useful where cave/karst features (i.e., possible cave entrances) are spread more diffusely or homogeneously through the understorey, instead of being concentrated in discrete locations. The judgemental search is better for finding small features and is less costly if the experienced searcher can predict where features are more likely to be found or not found—search routes are designed and optimized accordingly.

The risk of not finding the features that may occur in unselected routes or adjacent zones is minimized by carefully designing search routes, adjusting the search intensity (i.e., stratified sampling), and by utilizing knowledgeable and experienced field workers.

Note:
In the course of preparing this review we have discovered a possible application to future searches for persons reported missing from caves unknown to the B.C. Cave Rescue organization.

REFERENCES

Paloc, H. Glossary of Karst Hydrogeology: A Selection of 49 Specific Terms. Bureau de Recherches Geologiques et Minieres. Orleans, France. (Géologiques et Minières)

Plants of Coastal British Columbia including Washington, Oregon and Alaska. Compiled and edited by Pojar, J. and MacKinnon, A. BC Forest Service, Research Program. Lone Pine Publishing. Vancouver, Canada. 1994.

British Columbia Industrial Health and Safety Regulations. Workers' Compensation Board of British Columbia.

A Statement of Crown Land Cave Policy and Administration. Province of British Columbia. Ministry of Lands, Parks and Housing. Parks and Outdoor Recreation Division. January 1981.

First Draft of Cave/Karst Management Guidelines for Vancouver Forest Region. Province of British Columbia. Ministry of Forests. Vancouver Forest Region. Recreation Section. March 1981.

A Method to Manage the Cave/Karst Resource within BC's Provincial Forests. Province of British Columbia. Ministry of Forests. Vancouver Forest Region. Recreation Section. August 1983.

Cave Management Handbook (Including Cave/Forestry Guidelines for the Vancouver Forest Region). Province of British Columbia. Ministry of Forests. Vancouver Forest Region. August 1990.

Stewardship of Cave and Karst Resources in BC: A Review of Legislation, Policy and Management. Prepared by G. G. Runka for the Recreation Branch, Ministry of Forests. G. G. Runka Land sense Ltd. July 1992.

Cave/Karst Management Handbook for the Vancouver Forest Region. Province of British Columbia. Ministry of Forests. Vancouver Forest Region. March 1994.

Cave/Karst Management Handbook for the Vancouver Forest Region. Province of British Columbia. Ministry of Forests. Vancouver Forest Region. May 1994.

Cave/Karst Management Handbook for the Vancouver Forest Region. Province of British Columbia. Ministry of Forests. Vancouver Forest Region. July 1994.

Outdoor Recreation and the Forest Practices Code of British Columbia: How outdoor recreation is managed under the Forest Practices Code. Ministry of Forests. Recreation Section. Range, Recreation and Forest Practices Branch. Province of British Columbia. February 1996.

Tahsish Cave/Karst Inventory Project. Conducted by Cave Management Services for BC Ministry of Forests. Report date: November 1982.

Draft Karst and Cave Resource Management: Forest-Wide Direction, Standards and Guidelines. United States Department of Agriculture, Forest Service, Tongass National Forest. June 1994.

Timber Tenure System in British Columbia. Government of British Columbia. Ministry of Forests. Resources, Tenures and Engineering Branch. (Unpublished brochure). March 1996.

R.J. Stathers et al. Windthrow Handbook for British Columbia Forests. Research Program Working Paper 9401. Ministry of Forests Research Program. 1994.

A Glossary of Karst Terminology. Geological Survey Water-Supply Paper 1899-K. Complied by Monroe, W.H. United States Government Printing Office. Washington. Second printing. 1972.

Industrial Health and Safety Regulation. Workers' Compensation Act. Province of Britsh Columbia. Consolidated January 14, 1994.

Syrotuk, William G. An Introduction to Land Search Probabilities and Calculations, Arner Publications, Westmoreland, New York. 1975.

NOTE: See below for associated figures. The glossary, addendum, and appendix from this paper are not included.

Figure 1a: Reconnaissance search - rectilinear layout

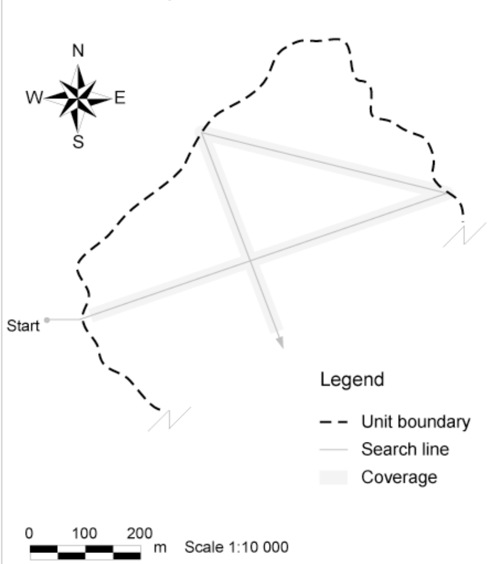


Figure 1b: Reconnaissance search - along projected road right-of-ways

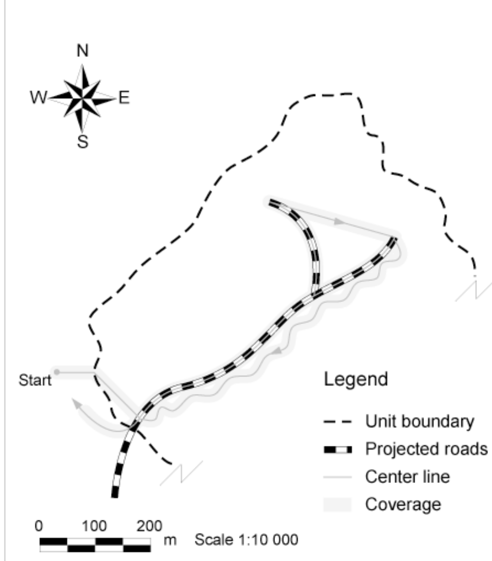


Figure 2: Strip search - 90-m center lines with lateral rovers

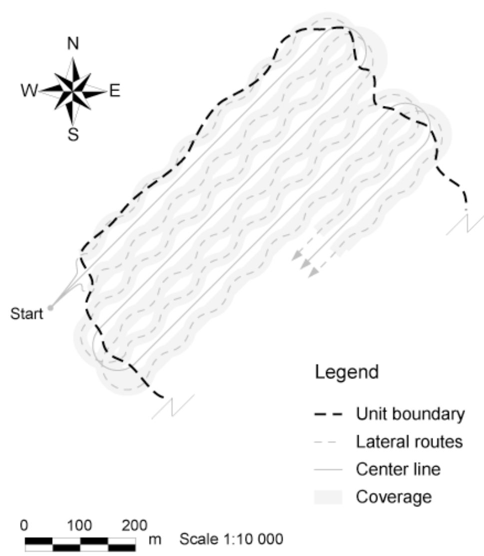


Figure 3: Judgmental search - along upper and lower contacts

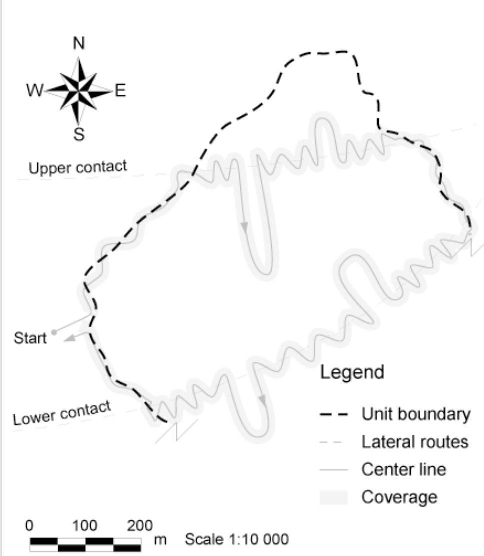


Figure 4: Total search

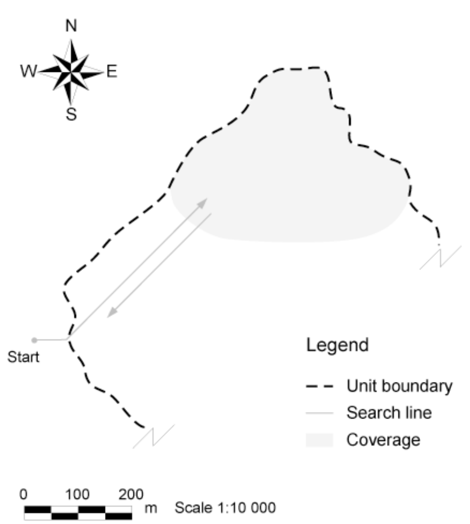


Figure 5: Swallet detection with judgmental search

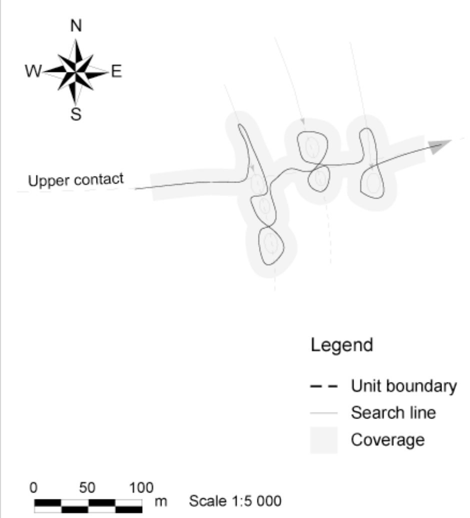


Figure 6a: Encountering fens with judgmental search

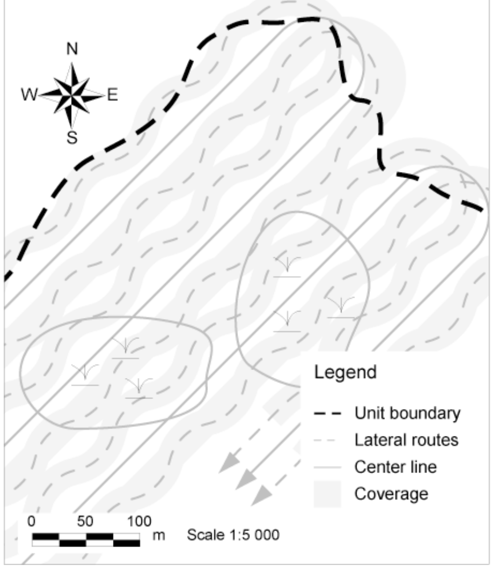


Figure 6b: Circumventing fens with judgmental search

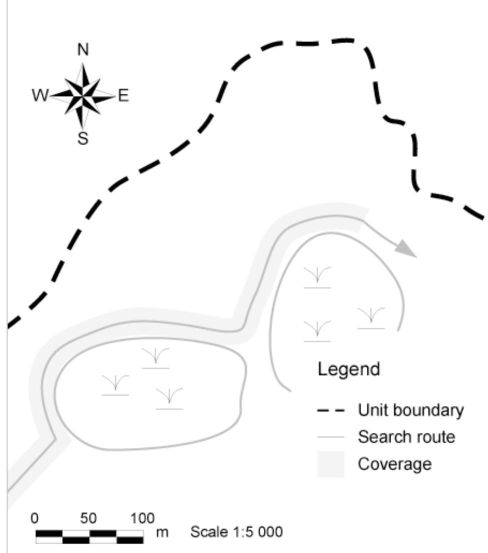


Figure 7: Amplitude versus frequency of lateral search routes

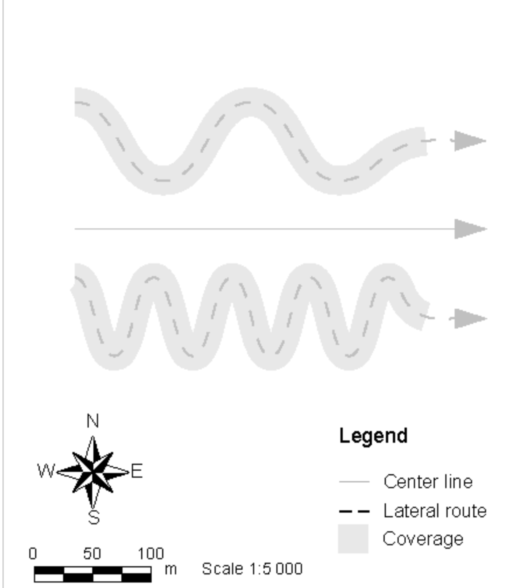
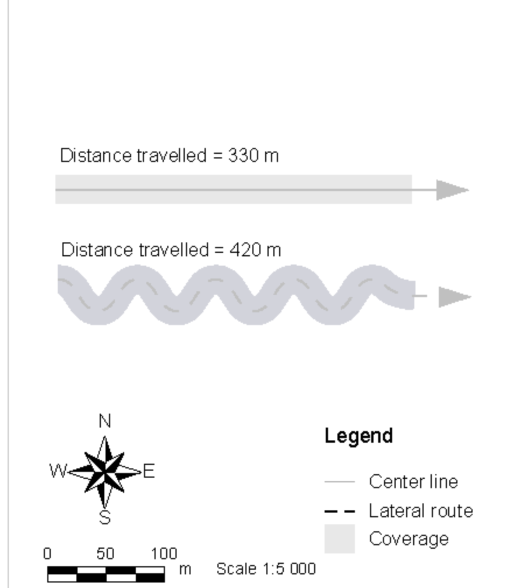


Figure 8: Distance travelled - center line versus lateral route



Appendix F. Example KFA field cards

KFA FIELD CARD #1 – SURFACE KARST FEATURE RECORD

Feature Id	Feature Type	Location	Dimensions (length/width/depth)	Description	Photo

KFA FIELD CARD #2 – SURFACE KARST FEATURE SIGNIFICANCE EVALUATION

DATE: Y	M	D	RECORDED BY:
KARST FEATURE NO.			LOCATION:
KARST FEATURE DESCRIPTION:			

Significance Criteria	Significance Potential			Unknown	Not Available	Comments
	Low	Mod.	High			
Dimensional Characteristics						
Connectivity						
Hydrology						
Geological						
Biological						
Scientific/Educational						
Archaeological/ Cultural						
Recreational/ Commercial						
Rarity/Abundance						
Visual Quality						

COMMENTS:

KFA FIELD CARD #3 – KARST VULNERABILITY ASSESSMENT

DATE:	RECORDED BY:
LOCATION:	POLYGON NUMBER:

EPIKARST DEVELOPMENT RATING: □ slight □ moderate □ high □ very high

Average soil thickness: □ bedrock □ <20 cm □ 20–50 cm □ 51–100 cm
□ 101–200 cm □ >200 cm

EPIKARST SENSITIVITY:

Epikarst Development Rating	Average Soil Thickness (cm)					
	>200	101–200	51–100	20–50	<20	Bedrock
Slight	Low	Low	Low	Low	Low	Moderate
Mod.	Low	Low	Low	Mod.	Mod.	Moderate
High	Low	Low	Mod.	Mod.	High	High
Very High	Low	Low	Mod.	High	Very High	Very High

Erodible, fine-textured soils present: □ yes □ no

(If yes, raise Epikarst Sensitivity Rating by one level)

EPIKARST SENSITIVITY RATING: □ low □ moderate □ high □ very high

SURFACE KARST FEATURE DENSITY: □ 0 □ 1–5 □ 6–10 □ 11–20 □ >20

SURFACE KARST SENSITIVITY:

Epikarst Sensitivity Rating	Surface Karst Feature Density				
	0	1–5	6–10	11–20	>20
Low	Low	Low	Mod.	High	High
Mod.	Low	Mod.	Mod.	High	High
High	Mod.	Mod.	High	High	Very High
Very High	Mod.	High	High	Very High	Very High

KARST ROUGHNESS RATING: □ smooth □ moderate □ high □ very high

(If high or very high, raise Surface Karst Sensitivity Rating by one level)

SURFACE KARST SENSITIVITY RATING: □ low □ moderate □ high □ very high

KFA FIELD CARD #3 (CONTINUED)

SUBSURFACE KARST POTENTIAL:

Subsurface Karst Potential Rating	Caves	Large-scale Negative Relief Features	Surface Watercourses
Low	No known caves	No large-scale negative relief features	Surface watercourses present with no evidence of water loss or gain
Moderate	Evidence of caves or suspected caves (possible cave entrances)	At least one large-scale negative relief feature	Losing and/or gaining watercourses present OR Sinking and/or rising watercourses present
High	Known caves	More than one large-scale negative relief feature	No surface watercourses

SUBSURFACE KARST POTENTIAL RATING: □ low □ moderate □ high

KARST VULNERABILITY:

Surface Karst Sensitivity Rating	Subsurface Karst Potential Rating		
	Low	Moderate	High
Low	Low	Low	Moderate
Moderate	Low	Moderate	High
High	Moderate	High	Very High
Very High	High	Very High	Very High

Unique or unusual karst flora/fauna or habitats present: □ yes □ no

(If yes, raise Karst Vulnerability Rating by one level)

KARST VULNERABILITY RATING: □ low □ moderate □ high □ very high

GEOMORPHIC HAZARDS: ______________________________

RECOMMENDATIONS: ______________________________

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