Saskatchewan
Environment

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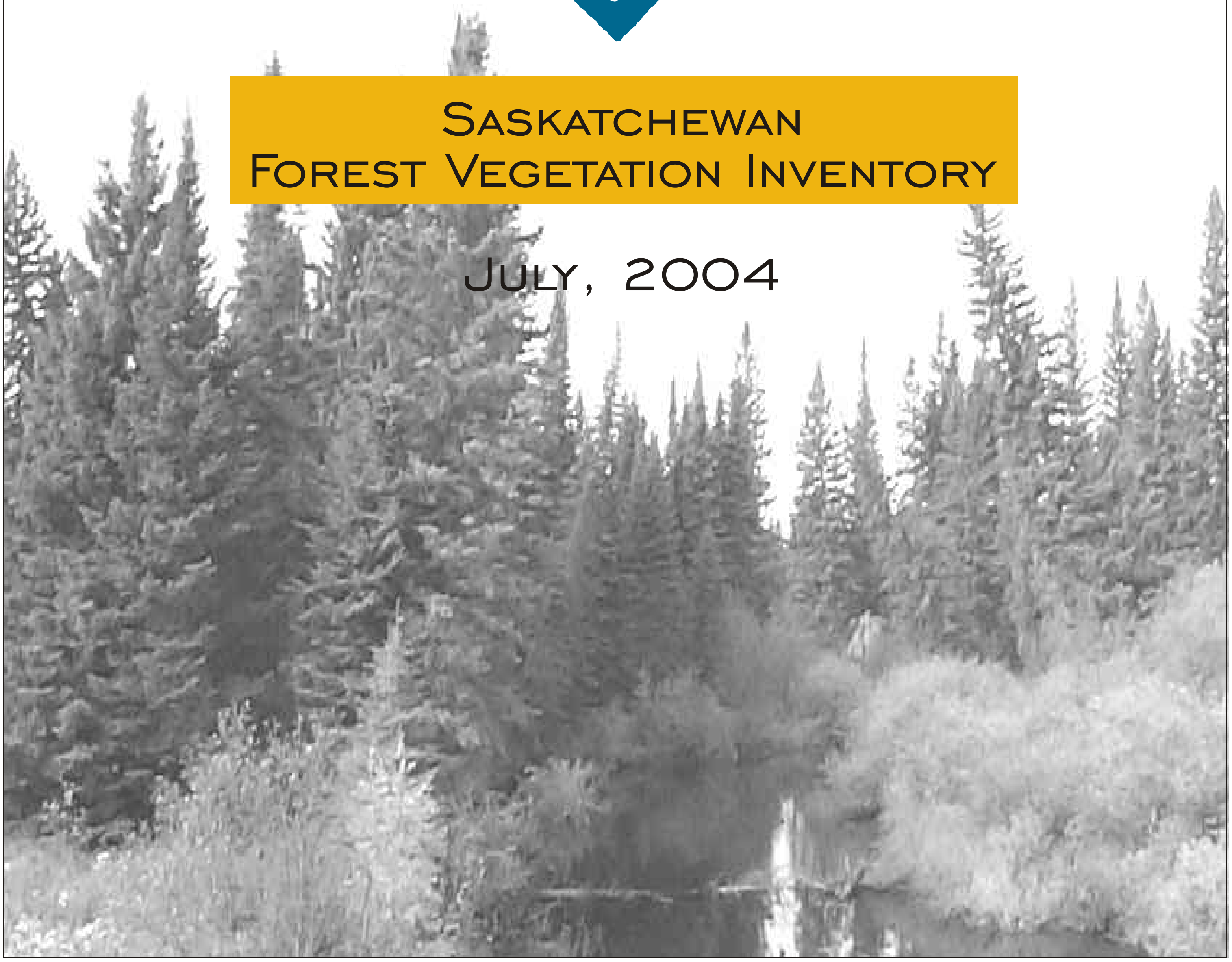
Saskatchewan Forest Vegetation Inventory

July, 2004



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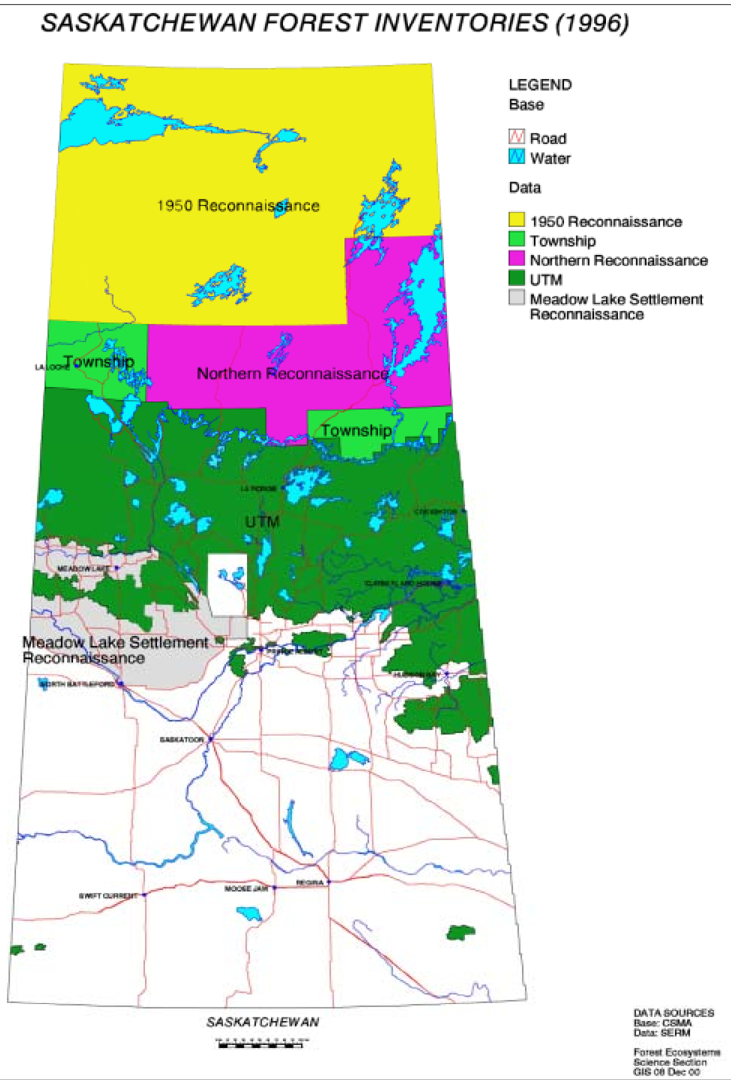
1.0 Introduction

The provincial forests of Saskatchewan cover about 35.5 million hectares or 55% of the Province (65.2 million hectares). These forests are concentrated in the Taiga Shield, Boreal Shield, and Boreal Plain Ecozones. Forest or forested lands also occur outside of the provincial forest boundaries and account for an addition 2.8 million hectares.

Figure 1. The provincial forest boundary and inventory systems applied to Saskatchewan's provincial forest.



Given the expanse of area and land use patterns, over 5 different inventories have been used to document the provincial forest land base, each with different levels of resolution, scale, and classification. The primary five inventories are the:

- 1950 Reconnaissance
- Northern Reconnaissance
- Township inventory
- Universal Transverse Mercator (UTM) inventory
- Meadow Lake Settlement Reconnaissance.

The UTM inventory covers the current commercial forest zone which is largely represented by the Mid-Boreal Upland and Lowland Ecoregions. The UTM inventory provides basic timber and site information. Since basic timber information will not meet the needs of current or future ecosystem-based management, new classifications and mapping standards have been developed and greater resolution of information has been recorded. These new standards reflect the needs of a variety of resource users, provide integration of disciplines, closely resembles the inventory standards for Alberta, and will provide the fabric for forest ecosystem-based management (*i.e.*, the ecosite).

1.1 About This Document

Saskatchewan's provincial forests provide many benefits; food and shelter for many species of wildlife, regulation of the water cycle, up-take of carbon dioxide, the production of oxygen, and employment for many individuals. Resources this valuable must be managed for the long-term with a strategic focus on sustainability. One document designed to provide a provincial forest strategy is the Forest Management Policy Framework, developed in 1995. Under this framework, Saskatchewan Environment identified eight strategic directions for forest management including:

- Stewardship of Forest Ecosystems
- Sustainable Use of Forest Resources
- Multiple Benefits
- Environmental Protection
- Public Involvement
- Aboriginal Participation
- Sustainable Management of Forest Resources on Private Lands
- Improved Decision-Making and Information Management (Anon. 1995a)

The Policy Framework is being implemented through the Long-Term Integrated Forest Resource Management Plan (Anon. 1995b). The purpose of the plan was to identify specific issues and develop strategies that would seek to balance the need to maintain and enhance the long-term health of our forest ecosystems with the need to provide economic, social and cultural opportunities for the benefit of present and future generations.

Of the strategies identified in the Long-Term Integrated Forest Resource Management Plan, improving inventory information was defined as a requirement to providing better management of the forest. Many of the other strategies also depend on the availability of a comprehensive multi-resource inventory because one of the chief obstacles to improved management of our forests is insufficient information on various components and processes of the forest. The past inventories lacked information on landform features, elevation, ecological land classes and non-timber components of the forest.

1.2 Purpose

The information requirements to properly carry out ecosystem-based management are substantial. The basis for good resource management is a good inventory, expressed both in terms of the individual features of the site and in some related or linked context. While this manual describes the features of the site, it is one of many components that make up an inventory. Other components associated with a comprehensive inventory process and design include a series of manuals and or field guides describing features such as: orthophoto-based base mapping, landform classification and mapping, ecosite and ecoelement identification and mapping, volume estimation and sampling, growth and yield remeasurement, and Geographic Information System (GIS) database design and coding structure.

The purpose of this manual is to identify the minimum inventory standards for defining and recording vegetation and site data as well as photo interpretation elements. This will help ensure that user needs are met and to ensure consistency of information collected.

1.3 Development Process

In 1991, the Forest Inventory section of the Forestry Branch of Saskatchewan Environment and Resource Management (SERM), initiated an extensive internal review of inventory processes and procedures to determine the changes necessary to meet the present and future information needs of the department and clients. Teams were formed to investigate, review and recommend changes in the following areas:

- Classification
- Mapping
- Geographic Information Systems (GIS)
- Sampling
- Analysis.

Although the teams were largely composed of inventory section staff, other client groups within SERM were involved on an ad hoc basis. Over the course of the next few years, a number of features were studied to test proposed changes in the inventory (Anon. 1992). The features that were assessed included species identification and composition, height, age, and crown closure classification, and drainage and landform classification. All of the proposed attribute changes passed the statistical evaluations with the exception of age. The stand age proved difficult to ascertain beyond decadal classes.

In 1996, Geomatics International was asked to review the status of the inventory program, the inventory review project, and recommend further steps to be taken. Some recommendations relevant to the inventory included:

- Move toward the role of provincial inventory administrator rather than sole creator of the inventory,
- Take the lead on developing partnerships with other government agencies and forest industry in developing and implementing a new inventory program,
- Integration of Global Positioning System (GPS) data with the inventory process,
- Adopt orthophoto-based base mapping processes, and
- Expand the photo-digitizing pilot study (Anon. 1996).

All of these recommendations have been implemented or initiated since that time. In 1997, SERM sponsored a Forest Inventory Planning Workshop. The goal of the workshop was to identify:

- Common interests of inventory information users,
- Any consensus which might exist on inventory requirements and priorities, and
- The next steps for implementation of a co-operative inventory effort.

Participants in the workshop included representatives from the following companies and agencies:

- Weyerhaeuser
- Mistik Management
- L&M
- Saskfor-MacMillan
- SaskGeomatics
- Prince Albert National Park
- and SERM offices:
    - Forestry Branch
    - Prince Albert Region
    - Fish & Wildlife Branch
    - Meadow Lake Region
    - Parks & Facilities Branch
    - La Ronge Region
    - Sustainable Land Management
    - Information Management Branch.

Participants identified weaknesses in the existing inventory and suggested additional information that provided a better description of terrestrial and wetland ecosystems. Suggested inventory changes ranged from changes in format or quantitative resolution (*e.g.*, height class description) to the addition of new thematic layers (*e.g.*, terrestrial and wetland ecosites, riparian zone) (Dempster 1997).

The workshop marked the turning point for the review process such that representatives from forest industry, SaskGeomatics, and Prince Albert National Park participated significantly in the review process from that point onward. Three committees were formed at the workshop and had the following responsibility:

1. Basemapping - responsible for establishing standards for an ortho-photo based basemap.
2. Classification - responsible for establishing the inventory standards, and
3. Data exchange - responsible for identifying issues, opportunities and constraints to the efficient exchange of digital inventory data within Saskatchewan Environment and between public and private sectors.

Between March 1997 and December 1999, the Classification Committee met eight times to review and revise the Forest Vegetation Inventory Standards Manual. Following that period, a working draft of the standards was operationally tested and a number of modifications occurred between 2000 and 2004. This publication is the result of that work.

1.4 General Design of the SFVI

The SFVI is intended to be an inventory principally based on the interpretation of stereo-paired black and white infrared aerial photographs normally produced at a scale of 1:15,000. Ground information, aerial reconnaissance, derived data, and other sources of information may also contribute to the development and update of the inventory database.

The inventory will be tied to the orthophoto base map. Each basemap data set will conform to a quadrangle covering an area of 10,000 metres x 10,000 metres and will be referenced to the 6° Universal Transverse Mercator Projection and the 1983 North American Datum (NAD83).

2.0 Photography Specifications

This section defines the specifications for aerial photographs and photography used in the creation of the Saskatchewan forest vegetation inventory.

2.1 Scale

Aerial photography used for SFVI interpretation will be printed in a 228 x 228 mm format at a standard scale of 1:15,000. Detailed example specifications for aerial photographs are found in Appendix I.

2.2 Camera & Film Specifications

Photos will be taken using a wide-angle lens, and black and white infrared film. The detailed camera and film specifications used for inventory and interpretation will be at least to the resolution and standards as defined by the specifications for aerial survey photography (Interdepartmental Committee on Air Surveys 1998) (Appendix II) with additions and modifications as defined in Appendix I. Some features expanded on from the ICAS specifications include:

- film type
- film density resolution
- camera type
- flight line direction / orientation.

3.0 Delineation

3.1 Basis for Delineation

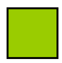
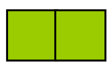
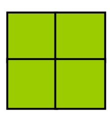
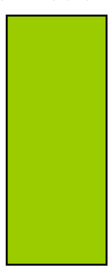
Delineation of the land base is based upon biophysical criteria that can be recognized and differentiated into homogeneous units by photo interpretation. Units with similar physical characteristics are delineated on 1:15,000 scale black and white aerial photographs. Accurate delineation reduces stand variation and improves the representativeness, reliability and usefulness of descriptions.

Delineation is carried out under stereoscopic viewing; preferably under magnification. While Table 1 presents the procedures to delineate polygons of different sizes, there are also cases where linear features cut through polygons (or other linear corridors) and there is an order of importance (or priority) for delineating these linear corridors. In order of priority, linear features should be delineated by: water feature, road, railway, pipeline, transmission line, and other.

3.2 Minimum Polygon Size Guidelines

While polygons are derived by a contiguity of site characteristics, the minimum polygon size is somewhat flexible. Differences in certain features or combinations of features may produce smaller polygons. The recommended minimum polygon size and the associated features required to create the smaller polygon are defined in Table 1. It is recognized that ownership, may produce smaller polygons than the recommended minimums.

Table 1. Summary of features distinguishing polygons.

Size (at 1:15 000)	**Distinguishing Features for Recommended Polygon Sizes**
One hectare 	• Water bodies will be delineated where the banks are > 15 m apart. This delineation is consistent with the widening of streams and pools along streams to reflect their true shape. • Land use clearings are justification for creating polygons as small as 1 ha.
Two hectares 	• Any classification within a land use clearing. • Any contiguous lower canopy change within a tree canopy classification (*i.e.*, same overstory/primary canopy, different understory/subcanopy). • Any significantly observable feature (*e.g.,* a wetland ecosite classification within a terrestrial ecosite classification, a leave patch within a cutover).
Four hectares 	• Any distinguishable wetland ecosite within a different wetland ecosite. • At least one of the following will be different: ○ Ecosite ○ Topography • At least two of: ○ Main canopy vs. lower canopy - closure differs by 20% ○ Tree species closure - primary species differs by 20% ○ Tree heights - either primary species groups differ by three metres. ○ Age differs by twenty years ○ Understory species composition is different ○ Soil moisture regime differs by one moisture class
Ten hectares 	• At least one of: ○ Main canopy vs. lower canopy - closure differs by 20% ○ Tree species closure - primary species differs by 20% ○ Tree heights - either primary species groups differ by three metres. ○ Age differs by twenty years ○ Understory species composition is different ○ Soil moisture regime differs by one class

3.3 Minimum line spacing

The standard for line spacing is never closer together than 1 mm (15 metres at 1:15,000). Occasionally this restriction may create polygons smaller than the guidelines expressed on Table 1.

Water bodies with a width greater than 15 m will have both sides of their banks defined. Linear (transportation) features (*e.g.*, rights of way) with a width greater than 15 m will have their boundary delineated

3.4 Linear features

While Table 1 presents the procedures to delineate polygons of different sizes, there are also cases where linear features cut through polygons (or other linear corridors) and there is an order of importance (or priority) for delineating these linear corridors. In order of priority, linear features should be delineated by: water feature, road, railway, pipeline, transmission line, and other.

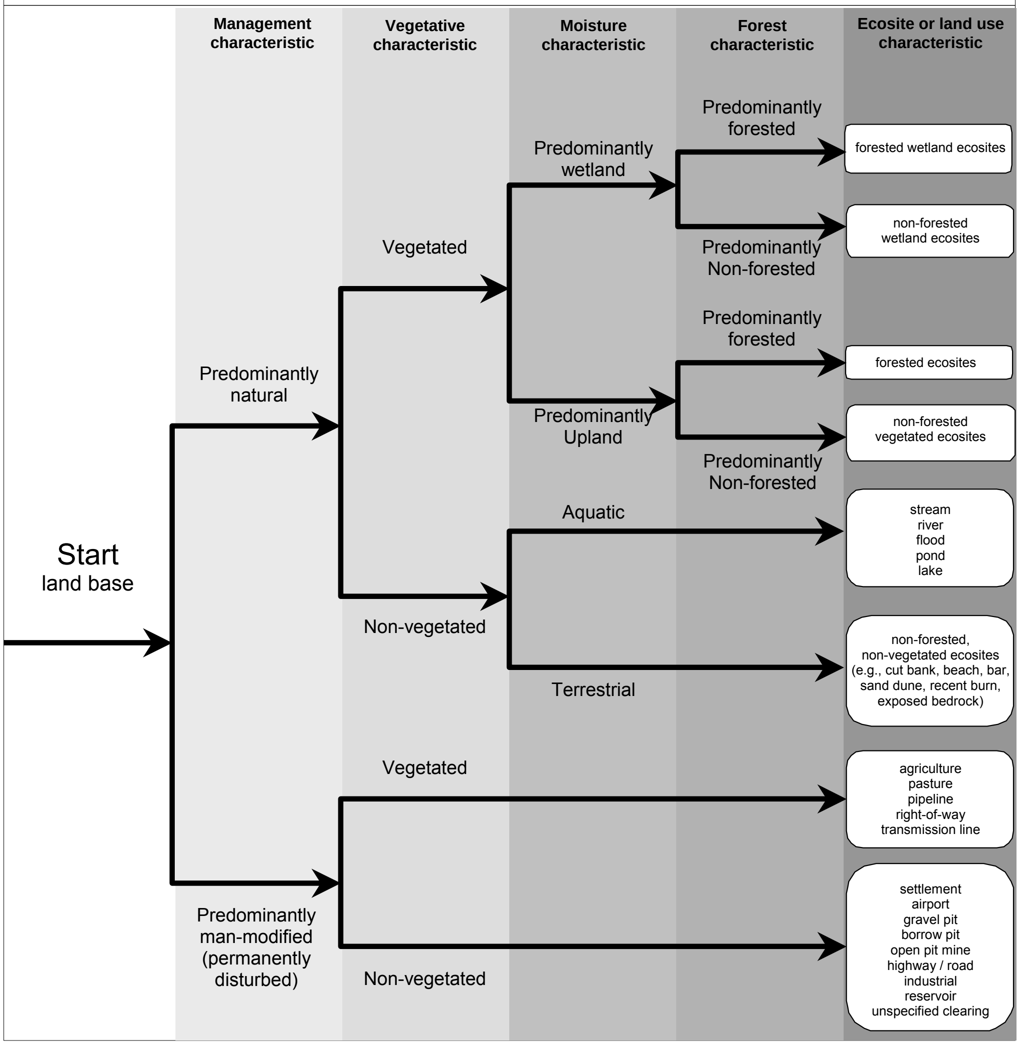
4.0 Classification Overview

Many processes, some natural and some anthropogenic have shaped Saskatchewan's landscape. Human activities on the landscape can leave lasting visual signatures such as roads, gravel pits, and even agricultural activities. While these features can remain visible for many decades, other human activities, such as well-planned and implemented forest management activities can be obscured by natural processes or return to mimic natural conditions in only a few years.

Typically, the greatest impact on the site, at least visually, is on the vegetation that occupies the site. And the feature that sets the path for which vegetation can establish itself is the moisture availability. The combination of these characteristics defines or describes the site not only in terms of composition, but also in terms of structure and function.

The delineation of sites on this basis moves resource management ahead by acknowledging that components of the ecosystem are related and must be considered as a whole such that actions affecting one component are felt across the entire matrix. Figure 2 provides an overview of how components of the inventory contribute toward the definition of ecological conditions.

Figure 2. Overview of the Saskatchewan forest inventory classification approach.



5.0 Description of Biotic Features

Within this inventory structure, all sites whether dominated by vegetation or not will be delineated and classified. All polygons except those sites belonging to the defined land-use categories will receive a vegetation description. Polygons with ≥6% vegetation cover will be considered vegetated in this manual. The vegetated category need not be listed in the inventory database as it is derived from the crown closure values associated with the tree layer, shrub layer, and herb layer.

The general forms of vegetation (*e.g.*, tree, shrub, herb) will be described independently. While some of these features are readily described through photo-interpretation (*i.e.*, trees), other components are best identified from field surveys (*e.g.*, herbaceous). In addition to the biotic layers is a layer that will describe the non-vegetated surface condition (*e.g.*, rock, sand, other mineral soil). The non-vegetated surface layer is described in section 6.1.

5.1 Tree Layer

The standards for tree layer include native and non-native species that exhibit tree form. For the purpose of this document a tree will be defined as a single stemmed perennial plant growing to a height of more than 3 m (Hosie 1979). Woody plants such as alder, willow, mountain maple, or hazel are not included in the tree layer.

Polygons with ≥6% tree cover shall be considered forested in this manual. The forested category need not be listed in the inventory database as it is derived from the crown closure value associated with the tree layer.
The defined polygon in the aerial photograph stereogram in Figure 3 illustrates the attribute examples referred to in sections 5.1.1 - 5.1.5.

5.1.1 Species Composition

The species composition standard describes the contribution of tree species to the overall tree cover that occur in a particular layer expressed in 10% percent crown closure classes. Composition will be identified in descending order of crown closure. The sum of the tree species components must equal 10 (100%) per layer. A maximum of 6 species per tree layer may be listed. The species to be included in the tree component and their numeric code are listed in Table 2.
An example polygon label illustrating species composition is as follows:

Example: Detailed polygon label showing the species composition of a mixedwood stand.

68% - 18 tA_7wS_3 - P5 – 1920d

30% white spruce

70% trembling aspen

Figure 3. Aerial photograph stereogram (1:15,000) showing a mixedwood forest (outlined in red) with the following attributes:

crown closure:	68%
tree layer height:	18m
species composition:	70% tA and 30% wS
canopy pattern:	P5 (openings common)
year of origin:	1920 d (decadal estimate)

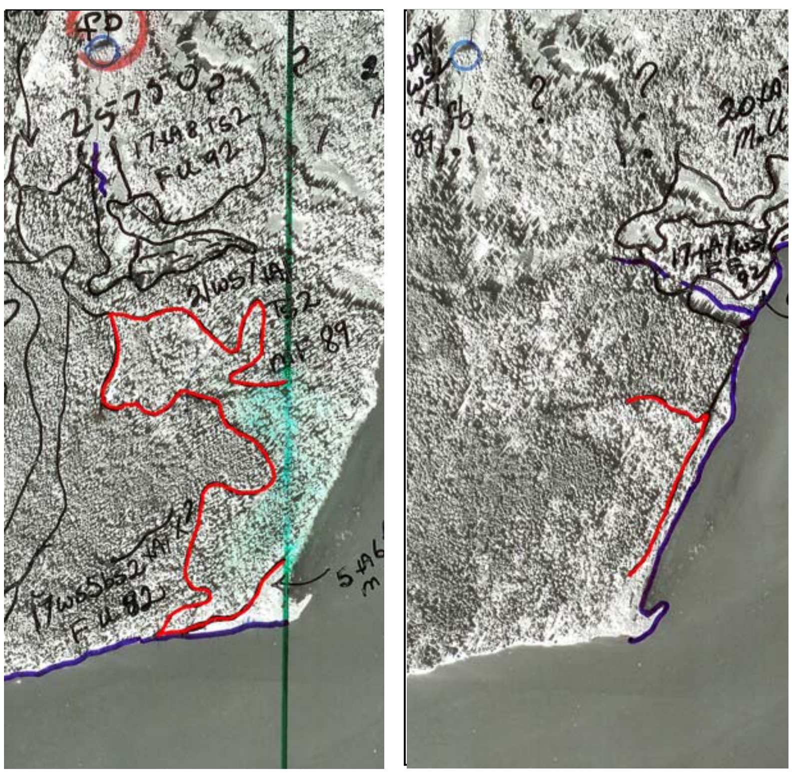


Table 2. Tree species and their respective character and numeric code.

Species Common Name	**Species Character**	**Numeric Code**	**Scientific Name**
White spruce	wS	01	*Picea glauca* (Moench) Voss
Black spruce	bS	02	*Picea mariana* (Mill.) B.S.P.
Jack pine	jP	03	*Pinus banksiana* Lamb.
Balsam fir	bF	04	*Abies balsamea* (L.) Mill.
Tamarack	tL	05	*Larix laricina* (Du Roi) K. Koch
Lodgepole pine	lP	06	*Pinus contorta* Dougl. ex. Loud.
Trembling aspen	tA	07	*Populus tremuloides* Michx.
Balsam poplar	bP	08	*Populus balsamifera* L.
White birch	wB	09	*Betula papyrifera* Marsh.
Green ash	gA	10	*Fraxinus pennsylvanica* Marsh.
Manitoba maple	mM	11	*Acer negundo* L.
White elm	wE	12	*Ulmus americana* L.
Bur oak	bO	13	*Quercus macrocarpa* Michx.
Red pine	rP	14	*Pinus resinosa* Ait.
Scots pine	sP	15	*Pinus sylvestris* L.
Siberian larch	sL	16	*Larix sibirica* Ledeb.
Plains cottonwood	pC	17	*Populus deltoides* var. *occidentalis* Rydb.

5.1.2 Crown Closure

The crown closure standard describes the percentage of ground area covered by the vertical projection of the tree crowns onto the ground. Crown closure is expressed for each distinct layer of vegetation. It is expressed to the nearest 1% and cannot exceed 100% for any individual layer (*e.g.,* polygon label below). Crown closure of each layer is based on the dominant and co-dominant trees associated with that layer. The smallest crown closure possible for any layer is 1% and the greatest is 100%.

Crown closure determination for mixedwood stands requires special consideration when the majority of the conifer crown occurs beneath those of the hardwoods. In these cases, it is particularly useful to utilize the aspects of stereoscopic vision to "see around" the hardwood canopy.

Example: Detailed polygon label showing the crown closure descriptor.

68% - 18 tA_7wS_3 - P5 – 1920d

68% crown closure of this canopy layer (tA wS)

5.1.3 Canopy Pattern

The canopy pattern standard describes the spatial arrangement of the trees by layer in a polygon. The canopy pattern is applied to each tree layer of stands with multiple distinct canopies (*e.g.,* polygon label below). There are six classes of canopy patterns. Figure 4 presents a visual representation of the canopy patterns from an overhead view, a description of each of the patterns, and the canopy code for the patterns.

Example: Detailed polygon label showing the canopy pattern descriptor

68% - 18 tA_7wS_3 - P5 – 1920d

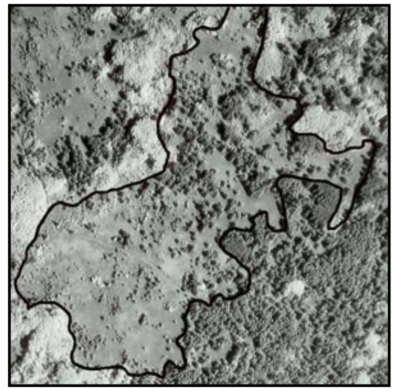
continuous canopy (P5) - openings common

Patches and opening are considered to be less than 2 hectares in size.

Figure 4. A description of the categories of canopy pattern.

Canopy Pattern P1
Single stems
Evenly spaced

Crowns rarely interlock and spacing is uniform. Crown closure is less than or equal to 50%



Canopy Pattern P2
Several patches of stems
Unevenly spaced

There are greater than or equal to 1 patch per 2 hectares. For polygons less than 5 ha, 3 patches are the minimum.

Canopy Pattern P3
Few patches of stems

There are less than or equal to 1 patch per 2 hectares. For polygons less than 5 ha, 3 patches are the maximum.

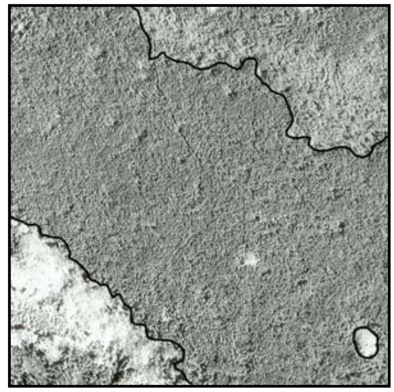
Canopy Pattern P4
Several patches of stems
Evenly spaced

There are greater than 1 patch per 2 hectares. For polygons less than 5 hectares, 4 patches is the minimum.

Figure 4. A description of the categories of canopy pattern. (continued)

Canopy Pattern P5
Continuous canopy
Openings common

Crowns interlock and crown closure is greater than 50%.



Canopy Pattern P6
Continuous canopy
Openings uncommon

Crowns interlock, spacing is uniform, and crown closure is greater than 50%.

5.1.4 Height

The height standard is the average height in metres of the dominant and co-dominant trees of the leading species for each tree layer within the polygon. Height is estimated to the nearest metre for each layer. Adjacent polygons must differ by at least 3 m before they are separated on the basis of height alone. The lower tree layer must differ by 3 m before being defined as a separate layer. All species within 3 m of the dominant species component of the layer will occur on the same label line (*e.g.,* polygon label below).

Example: Detailed polygon label showing the height descriptor

68% - 18 tA_7wS_3 - P5 – 1920d

18 m trembling aspen and white spruce (or white spruce within 3 m of the leading species)

5.1.5 Year of Origin

The standard for year of origin is the year in which the trees are believed to have germinated. Year of origin is assigned to the co-dominant/dominant leading species of each tree layer.
Year of origin may be recorded to the nearest year or nearest decade depending on the information available to the interpreter. Estimates to the nearest year will be designated with "a" (for annum), while estimates to the nearest decade will be designated with a "d" (for decadal). Estimates will be recorded using all 4 digits of the year.

Decadal classes will represent the approximate mid-point of the estimated decadal year of origin (*e.g.,* 1950 d represents a stand containing trees that have an estimated year of origin within the range from 1946 to 1955).

The year of origin can be calculated from fire records or by ring counts of cores collected from trees and then adjusted by the addition of a correction factor.
The standard age correction factor for Saskatchewan tree species can be seen in Table 3. This table assumes that both softwoods and hardwoods have been cored at diameter-at-breast-height (D.B.H.). Where accurate assessments of site, species, and growing conditions are available, the standard age adjustment may be modified accordingly.

Example: Detailed polygon label showing the year of origin descriptor

68% - 18 tA_7wS_3 - P5 – 1920d

A 1920 year of origin
- estimated to nearest decadal class

5.1.6 Tree Layer Types

Within each forested polygon there may be one or more layers. Layers are distinguished in this inventory according to the height characteristics of the species in the stand. In addition to tree layers, there may also be other vegetated and non-vegetated layers (*i.e.*, shrub [5.2], herbaceous layer [5.3], non-vegetated surface layer [6.1]). Tree layers may occur as single, multiple or complex forms. The standards for tree layers are as follows.

5.1.6.1 Single Layer

If the trees in a polygon are within 3 metres of the height of the dominant and co-dominant trees of the leading species, then a single layer exists. The previous example polygon labels describe the single canopy condition.

Table 3. Tree species and their respective age adjustment factor for trees cored at 1.3 m (D.B.H).

Species	Age adjustment factor
White spruce	15
Black spruce	20
Jack pine	8
Balsam fir	7
Tamarack	12
Lodgepole pine	8
Trembling aspen	4
Balsam poplar	4
White birch	5
Green ash	7
Manitoba maple	4
White elm	10
Bur oak	10
Red pine	8
Scots pine	9
Siberian larch	12
Plains cottonwood	4

5.1.6.2 Multiple Layer

To be defined as a multi-layer stand, tree layers must differ by 3 m before being defined as a separate layer. All species within 3 m of the dominant species component will form the first layer. All species within 3 m of the next layer will form the next layer and so on. Each layer will be assigned its own species composition, crown closure, height, canopy pattern, and year of origin (*e.g.,* polygon label below). The layers will be listed with the tallest first and shortest last, as in the examples provided. A maximum of three tree layers will be permitted per polygon.

Example: Detailed polygon label showing a multiple (two-canopy) condition

68% - 22 tA_6wS_4 - P5 - 1921a

22% - 12 wS_{10} - P2 - 1940d

2nd Canopy Characteristics

An estimated 1940 decade of origin

Several patches of stems – Unevenly spaced canopy pattern

This canopy is entirely 12 m white spruce

This canopy covers 22% of the ground

Example: Detailed polygon label showing a multiple (three-canopy) condition

23% - 22 tA_6wS_4 - P1 - 1921a

22% - 12 wS_{10} - P1 - 1940d

10% - 7 bF_{10} - P1 - 1950d

3rd Canopy Characteristics

An estimated 1950 decade of origin

Evenly spaced single stems canopy pattern

This canopy is entirely 7 m balsam fir

This canopy covers 10% of the ground

Figures 5 and 6 illustrate the three-canopy forest condition with cross-sectional and aerial oblique views respectively. Figure 7 illustrates the three-canopy condition with an aerial photograph stereogram.

5.1.6.3 Complex Layer

Stands with complex layer conditions exhibit a high variation in tree heights. There is no single definitive layer as nearly all height classes (and frequently ages) are represented in the stand. The height chosen for a complex stand is the median or from the mid-point such that 50% of the trees are taller than the point chosen and 50% are shorter. This value represents the mid-point of the range or 'inter-range value'. The year of origin provided in these conditions will be that associated with the inter-range height provided.

The polygon label (*e.g.,* polygon label below) designating complex layers will also indicate the height 'tolerance value' that is added and subtracted from the inter-range value. The terms inter-range and tolerance are used so as not to be confused with measures of standard error or confidence interval that refer to statistical calculations.

Complex layer designations will only be associated with the following conditions:

- wetland - poor site leading black spruce and or leading tamarack,
- stands with balsam fir as the leading species,
- open grown jack pine frequently associated with mistletoe, and
- very shallow soil / poor site conditions of jack pine / black spruce on the Boreal and Taiga Shield ecoregions.

Example: Detailed polygon label showing complex canopy condition

58% - 10C4 bS$_6$tL$_4$ - P4 - 1920d

The complex stand ranges in height from 6 to 14 m (*e.g.*, 10±4)

Figure 5. Cross-section view of a three-canopy stand.

Figure 6. Oblique view of a three-canopy stand.

Figure 7. Aerial photograph stereogram (1:15,000) showing a stand with three canopy layers (outlined in red).

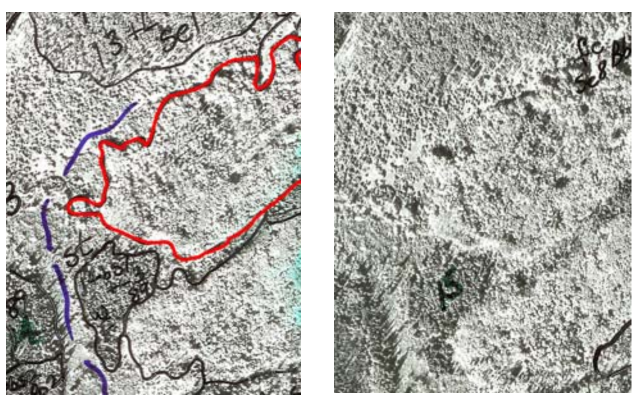
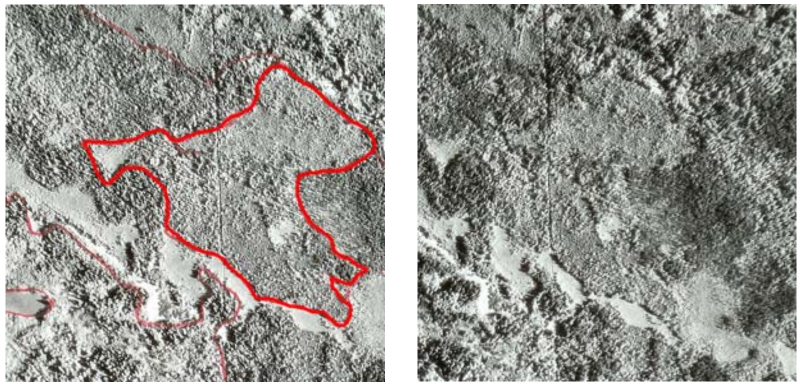


Figure 8. Aerial photograph stereogram (1:15,000) showing a stand with a complex canopy (outlined in red).



5.2 Shrubs

The shrub layer includes native species that exhibit shrub form. Shrubs are considered to be multiple stemmed woody perennial plants that typically do not grow more than five metres tall. The standards for shrub layer will be classified as tall shrub (Ts), typically ≥2 m or low shrub (Ls), <2 m, or by species where it is known. The shrub label will follow all of the tree canopy labels if more than one exists.

When some form of ground survey data is available, this information may be included in the database. In closed forest canopy conditions, this attribute may be difficult, if not impossible to determine, especially to species level of detail. This category may be estimated by photo-interpretation to the tall or low shrub category in conditions where it can be seen such as open forest canopy or non-forested conditions or supported by field data.

5.2.1 Species Composition

The species composition standard describes the contribution of shrub species to the overall shrub cover that occur in the shrub layer expressed in 10% percent crown closure classes. Composition will be identified in descending order of crown closure. Shrub species composition is recorded in 10% classes per shrub layer (*e.g.*, polygon label below). The sum of the shrub species components must equal 10 (100%). A maximum of 10 species per shrub layer may be listed. The species to be included in the shrub component and their respective category are listed in Table 4. Where known, the species will be listed. Where unknown, the general category will be used.

Example: Detailed polygon label showing the shrub layer descriptor where the species are known

58% - 22 tA_6wS_4 - P5 - 1921a

44% - $Bh_6Wi_2Pc_1Ro_1$

10% rose
10% cherry
20% willow
60% beaked hazel

Example: Detailed polygon label showing the shrub layer descriptor where the species are unknown

58% - 22 tA_6wS_4 - P5 - 1921a

44% - Ts_9Ls_1

10% low shrubs
90% tall shrubs

5.2.2 Crown Closure

The crown closure of shrubs standard is the percentage of ground area covered by the vertical projection of the shrub crowns onto the ground. It is expressed to the nearest 1% and cannot exceed 100% (*e.g.*, polygon label below). Crown closure of the shrub layer is based on the average coverage of both the tall and low shrubs.

Example: Detailed polygon label showing the shrub crown closure descriptor

58% - 22 tA_6wS_4 - P5 - 1921a

44% - $Bh_6Wi_2Pc_1Ro_1$

44% crown closure of the shrub layer

Table 4. Shrub species and their respective character code.

Species Common Name	Species Character Code	Notes
Tall Shrub category	Ts	
Alder	Al	Includes green alder and river alder
Beaked hazel	Bh	
Mountain maple	Ma	
Saskatoon berry	Sa	
Pin cherry	Pc	Includes pin and choke cherry
High-bush cranberry	Cr	
Willow	Wi	Includes all willows
Low Shrub category	Ls	
Prickly rose	Ro	
Bog birch	Bi	
Buffaloberry	Bu	
Red-osier dogwood	Dw	
Wild red raspberry	Ra	
Currant	Cu	Include all currants and gooseberries
Western snowberry	Sn	
Blueberry	Bb	
Shrubby cinquefoil	Ci	
Bog laurel	Bl	
Labrador tea	La	
Leatherleaf	Le	
Bearberry	Be	
Low-bush cranberry	Lc	

5.3 Herbaceous

Herbs are non-woody vascular plants, but for the purposes of this document, this category includes bryophytes and lichens. Both species composition and crown closure determination for herbs is difficult (virtually impossible) to ascertain from aerial photography alone and the general category designations will likely be used. When some form of ground survey data is available, this information may be included in the database. Where known, the species will be recorded otherwise the general category designation may be used. The herbaceous category (including composition and crown closure) is standard within the inventory such that the information can be accommodated in the database.

5.3.1 Species Composition

The herbaceous species composition is the contribution of herb species to the overall herbaceous cover expressed in 10% percent crown closure classes (*e.g.*, polygon label below). Composition will be identified in descending order of crown closure. The sum of the herb species components must equal 10 (*i.e.*, 100%). A maximum of 10 species in the herbaceous layer may be listed. The species to be included in the herb component and their respective category are listed in Table 5.

Where the species are known, they may be listed by their respective species code. Where the observer cannot readily identify the species, they may be listed by their category code (*e.g.*, herb, fern, grass, moss).

Example: Detailed polygon label showing the herb layer descriptor

58% - 22 tA_6wS_4 - P5 - 1921a

44% - $Bh_6Wi_2Pc_1Ro_1$

35% - $He_4Gr_3Mo_3$

30% mosses

30% grasses

40% unidentified herbs

5.3.2 Crown Closure

The crown closure standard is the percentage of ground area covered by the vertical projection of the plants onto the ground. It is expressed to the nearest 1% and cannot exceed 100%. Coverage of the herb layer is based on the average coverage of all herb categories.

Example of a detailed polygon label showing the shrub crown closure descriptor

58% - 22 tA_6wS_4 - P5 - 1921a
44% - $Bh_6Wi_2Pc_1Ro_1$
35% - $He_4Gr_3Mo_3$

35% coverage of assorted herbs, grasses, and mosses

Table 5. Herb and related category codes for use in the vegetation inventory[1].

Species Common Name	Species Character Code	Notes
Herb	He	Includes all herbs not listed below
Fern	Fe	Includes all ferns and fern allies
Grass	Gr	Includes grasses, sedges and rushes
Moss	Mo	Includes all feather and sphagnum mosses
Lichen	Li	
Aquatic vegetation	Av	Includes emergent, floating and submergent aquatic plants

[1] See Johnson *et al* (1995) for a more complete listing of common species associated with the categories of herb, fern, grass, moss, lichen, and aquatic vegetation.

5.4 Ecosites

Ecosites are site-level descriptions that provide the linkage between the biotic (*i.e.*, vegetation) and abiotic (*e.g.*, soils, moisture regime) features on the site. They also provide the linkage between planning and operations. Ecosites are ecological units that represent recognizable site conditions, and are also mappable units that can provide the basis for planning and modelling. The ecosite provides the single most descriptive piece of information on the polygon label. A great deal of detailed qualitative site information can be inferred from the ecosite. Other polygon attributes provide the quantitative description of the site. Ecosites are a standard attribute in the inventory.

When derived from ground-based information (the classification process) and developed in concert with photo-interpretable features (the regionalization process), they are mappable and provide information for habitat management, developing silvicultural and harvest prescriptions, and understanding natural and managed succession.

Baseline ecosite information for the mid-boreal ecoregions has been collected and documented by Beckingham *et al.* (1996). From 1999-2004, field sampling occurred on the sites under-represented in the mid-boreal guide, as well as from sites across the other forested ecoregions. With these data, the provincial forest ecosites will be developed and finalized within this inventory design. When the ecosite descriptions and labels are finalized, they will be included in the inventory database. Each polygon will receive an ecosite designation.

Both wetland and terrestrial ecosites will be defined such that the ecosite will be the feature that will guide the placement of "stand boundaries". Still using the regionalization process of division and subdivision based on visible differences in dominant vegetation, this process is tempered with the recognition that other factors play a role in placing site boundaries. Other processes or characteristics include slope, or slope position, aspect, amount of understory vegetation visible, available moisture, landform and soil characteristics. Many sources of information are available that provide methods to distinguish ecological units from aerial photographs; some include:

- *Ecological Classification of Saskatchewan's Mid-boreal Ecoregions using Resource Maps and Aerial Photographs* (Beckingham *et al.* 1999)
- *Forest Ecosystem Toposequences in Manitoba* (Zoladeski *et al.* 1998)
- *Training Manual for Photo Interpretation of Ecosites in Northwestern Ontario* (Arnup *et al.* 1999)
- *Building Aerial Photo Interpretation Keys to the NWO FEC S-types and V-types in the Roslyn Lake Study Area: A Case Study* (Johnson and Walsh 1997)

- *Photo Interpretations of the NWO FEC Vegetation and Soil Types for the Aulneu Peninsula: Northwestern Ontario* (G.M. Wickware & Associates 1989)

While aerial photography provides one method of determining ecosite, other means are available that rely on multiple databases (vegetation, soils, landform, ecodistrict, elevation, aspect, slope) to assign the ecosite designation. These software modelling approaches are also suitable for assigning ecosite. Three examples of this predictive ecosystem mapping approach include:

- ELDAR (Ecological Land Data Acquisition Resource) (Mulder, 1998)
- Site Logix (Beckingham *et al.* 1999)
- Fuzzy Logic (Nadeau *et al.* 2002).

The above methods for determining ecosite are guidelines.

6.0 Abiotic Features Description

The abiotic or non-living components of the inventory focus on aspects of the landscape that were largely shaped by the geological process of glaciation. This includes terrain features such as topography, soils, and hydrology.

6.1 Non-Vegetated Surface Layer

In addition to the vegetated layers (*i.e.*, tree layers, shrub layer and herbaceous layer) will be a non-vegetated surface layer where one exists. This layer is usually associated with barren conditions that are encountered on the Canadian Shield (*e.g.,* exposed bedrock, sparsely vegetated sand dunes). The standard is only one non-vegetated surface layer class associated with any polygon. Recognized non-vegetated surfaces are defined in Table 6.

Table 6. Non-vegetated layer classes

Non-vegetated layer	**Description**	**Class Code**
Unknown	An area absent of vegetation due to an undeterminable cause.	UK
Cutbank	The outside of river or stream meander, where the majority of erosion occurs.	CB
Rock	An area of exposed rock or boulder pavement (*i.e.,* felsenmeer); often associated with the Boreal and Taiga Shield ecozones.	RK
Sand	An area of exposed sand; often associated with dune conditions.	SA
Mineral soil	An area of exposed mineral soil (other than sand)	MS
Gravel	An area of exposed gravel (not gravel pits)	GR
Sandbar	An area of exposed sand in association with water	SB
Water	Areas of open / exposed water in association with vegetation	WA

6.1.1 Non-Vegetated Layer Coverage

The standard for coverage or extent of coverage of the non-vegetated layer is the percentage of ground area (*e.g.,* sand, rock) exposed. It is expressed to the nearest 1% and cannot exceed 100% (*e.g.,* polygon label below).

Example: Detailed polygon label showing the non-vegetated layer descriptor

35% - 12 jP$_6$bS$_4$ - P1 - 1921a

10% - Ls$_{10}$

25% - RK

25% coverage of exposed rock

6.2 Topographic Class

The topography class of a site describes the relief on the site and the percentage of vertical rise relative to horizontal distance. Six distinct classes of topography will be recorded. Topographic class can be assigned from aerial interpretation or from digital elevation models where available. Table 7 defines the standard for topography classes.

6.3 Soil Characteristic

Soils information will constitute a separate thematic layer. The basis for this information is from the Saskatchewan Soils Survey and subsequent soils maps of the northern provincial forest reserves (*e.g.*, Andersen and Ellis 1976).

6.4 Soil Moisture Regime

Soil moisture regime signifies the availability of moisture for vegetation growth. The moisture regime is a relative ranking of sites based on their available moisture supply. The availability of moisture is dynamic and varies throughout the year; the intent is to evaluate available moisture on the basis of the growing season as a whole. Class assignment is based upon the polygon average. The bolded moisture classes (dry, fresh, moist & wet) are the minimum class standard designations although the designation of "very or moderately" classes may be used when the need arises. Table 8 defines the standard soil moisture regime classes and descriptive characteristics for each class.

Table 7. Description of topography classes and associated range in slope[2].

Topography Class	Relief	Range of Slope (%)	Description
D	Depression	≤ 2	Flat or concave, lower in relation to surrounding topography
F	Flat	≤ 2	Essentially level. Less than 10% of the area occupied by low relief features exhibiting less than or equal to 2% slope.
U	Undulating	> 2 and ≤ 5	Area of gently sloping or undulating terrain. Differences in elevation will be less than 5% slope.
H	Hilly	> 5 and ≤ 15	Area of long gentle to moderate slopes, or very short steep slopes. Differences in elevation would reflect less than 15% slope.
S	Steep	> 15	Area of moderately steep long slopes or short very steep slopes. Differences in elevation frequently exhibit an excess of 15% slope.
G	Gully	5 - 100	Area of moderately steep long slopes or short very steep slopes. Differences in elevation frequently exhibit an excess of 15% slope. Typically, two opposite and relatively equal slopes with leading edges that are within 150 m of one another distinguish a ravine from a simple steep slope.

[2] % Slope is a measure of (vertical rise in elevation divided by the horizontal run) x 100
% Slope = 100 x tangent (º slope) ; º Slope = Arctangent (% slope) 100)

Table 8. Soil moisture classes and their associated descriptions.

Moisture Class Code	Moisture Regime	Typical effective Soil texture	Description
VD	Very Dry	Rock, gravel, very coarse sands	Soil retains moisture for a negligible period following precipitation and water infiltration is extremely rapid.
D	**Dry**	Rock, gravel, very coarse sands	Soil retains moisture for brief periods following precipitation and water infiltration is very rapid.
MF	Moderately Fresh	Loamy sand to sandy loam	Soil retains moisture for short periods following precipitation and water infiltration is rapid.
F	**Fresh**	Loamy sand to sandy loam	Soil retains moisture for moderately short periods following precipitation and water infiltration is moderate.
VF	Very fresh	Silty loams to sandy clayey loams and clays	Soil retains moisture for substantial periods following precipitation or in some cases seepage. Water infiltration is somewhat slow.
MM	Moderately Moist	Variable depending on seepage	Soil retains abundant moisture for most of the growing season. Water infiltration following precipitation and periodic seepage is slow. Mottling may occur below 20 cm.
M	**Moist**	Variable depending on seepage	Soil is wet for a substantial part of the growing season. Seepage is common with mottling below 20 cm.
VM	Very Moist	Variable depending on seepage	Soil is wet for most of the growing season. Permanent seepage and mottling are present and weak gleying may occur.
MW	Moderately Wet	Variable depending on seepage	Soil is wet for nearly all of the growing season. Permanent seepage and mottling is present, gleying in mineral soils, organic soils are also common.
W	**Wet**	Variable depending on seepage	Water table is at or near the surface (surface seepage) for most of the year. Gleying is common in mineral substrates and organic soils are also common.
VW	Very Wet	Variable depending on seepage	The water table is at or above the soil surface all year. Soils are organic or gleyed mineral.

(Adapted from Nesby 1997)

6.5 Aquatic Features

Aquatic features are standard within the inventory. They include all exposed water, both moving (*e.g.*, rivers, streams) and stationary (*e.g.*, lakes, floods, marshes). Aquatic features will occur as a separate layer in the GIS and will be connected where seen as connected; even through roads. Water boundaries will be delineated on both sides of the lake, river, or stream where the two visible edges are further apart than 15 m. Boundaries may be also be delineated at less than 15 m where interpretation technology or GPS field data exists.

While many of the aquatic features are provided during the topographic mapping process, additional aquatic features (*e.g.*, streams) will be captured during the 1:15,000 photo interpretation processes.

The aquatic features and associated description and coding are provided in Table 9.

Table 9. Aquatic feature codes

Feature	Description	Feature Code
Lake	A body of water. A solid blue line will define the water level as discernable on the aerial photograph at the time of photography. Where a fluctuating water line is visible, it will be indicated by a broken blue boundary.	LA
River	Rivers are a body of water flowing through a channel to a lake, marsh, or another river. A solid blue line will indicate the water line along the water edges. Flow direction of rivers and streams may be provided where known.	RI
Stream	A stream is a continuous body of flowing water, usually following a specified drainage pattern to a lake, marsh or river. The stream location will be shown with a single line to indicate the watercourse. Where streams widen beyond 15 m, both banks will be delineated. Streams will not be used as polygon boundaries unless they are greater than 15 m wide. Flow direction of rivers and streams may be provided where known.	ST
Intermittent Stream	Intermittent streams are bodies of water that are affected by seasonal precipitation, topography and soil texture. Intermittent stream location will be indicated by a single broken line and will indicate water flow, a definitive drainage pattern or obvious watercourse. Intermittent streams do not create polygon boundaries.	IS
Flood	Floods are areas that have been recently covered with water. Beaver dams or roads with insufficient allowance for natural drainage may cause flooding	FL
Seasonal Flood	Areas will be delineated as seasonally flooded where portions or all of the area have been damaged or show evidence of recent seasonal flooding.	SF
Flooded Borrow Pit	A pit that was created by the extraction of mineral resources that has subsequently filled in with water.	FP
Ditch	A relatively long narrow depression created to drain water	DI
Rapids	Part of a stream or river where the surface is disturbed due to underwater obstructions.	RA
Falls	A ledge over which water flows along a stream or river	FA
Reef	Rocks or sand partially or completely submerged beneath a lake surface	RF
Dam	A bank or barrier constructed to restrict or prevent the flow of water	DM

6.5.1 Snags

Before flooding, the land may have supported trees resulting in residual dead or dying trees (snags). The presence of snags may be denoted by a blue “SN” within the boundaries of the flood.

6.5.2 Beaver Lodges & Dams

The location of beaver lodges may be indicated with a blue “BL”. Beaver dams may be delineated as line features.

6.6 Disturbance Descriptions

Delineation of disturbances includes human activities such as harvesting activities and road construction. Natural disturbances such as burnovers and wind throw will also be delineated. With the exception of land-use clearings and roads, disturbance designations will not take the place of the vegetative or ecosite description and are provided to enhance the utility of the inventory. Disturbances occur as separate spatial layers.

A maximum of three disturbance feature codes (and their respective extent and year of occurrence) may be listed per polygon. As a guide, the features listed should be evident on the 1:15,000 aerial photographs. Disturbance features beyond 30 years of age will not be recorded. Disturbance features are standard in the inventory and their codes are listed in Table 10.

Disturbance features should be recorded in order from most recent to oldest.

Table 10. Disturbance features and their respective character codes.

Disturbance Feature	Code	Description
Cutover	CO	Areas will be delineated as cutover where portions or all of the forest cover have been manually or mechanically harvested.
Burnover	BO	Areas will be delineated as burnover where portions or all of the forest cover have been intentionally or naturally burned.
Windthrow	WI	Areas will be delineated as windthrow where portions or all of the forest cover have been uprooted or broken by wind.
Hail	HA	Areas will be delineated as hail damaged where portions or all of the forest cover have been affected by hail.
Insect	IN	Areas will be delineated as insect damaged where insects have damaged portions or all of the forest cover. The year of infestation should reflect the year of insect damage assessment.
Disease	DI	Areas will be delineated as disease damaged where portions or all of the forest cover have been damaged by disease. The year of infection should reflect the year of disease damage assessment.
Animal Kill	AK	Areas will be delineated as animal damaged or killed where animals have damaged portions or all of the forest cover (*e.g.*, aspen girdled or felled by beavers, grazing damage by cattle).
Snags	SN	A blue “SN” within the boundaries of the flood will denote the presence of snags.
Beaver Lodge	BL	Beaver lodge locations may be marked within polygons with the initials “BL”.
Slump	SL	Areas will be delineated as slumps where portions or the entire site have collapsed (usually on a slope).
Silviculture	SI	Areas will be delineated as silviculturally treated where portions or all of the area have been site prepared, planted, thinned, tended, fertilized or been subject to any other silvicultural treatment. Where further information is required on the specific type of treatment, silvicultural records should be consulted.

6.6.1 Extent of Disturbance

The extent of disturbance provides an estimate of the proportion of the polygon that has been affected by the disturbance listed. The standard for extent labels and proportion of the polygon affected are shown in Table 11.

Table 11. Extent of disturbance and its respective character code.

Extent	Extent code	Description
Light	1	1 – 25% of the area has been affected
Moderate	2	26 – 50% of the area has been affected
Heavy	3	51 – 75% of the area has been affected
Severe	4	76 – 94% of the area has been affected
Entire	5	95 – 100% of the area has been affected

6.6.2 Year of Disturbance

The year of disturbance is a standard and will be provided for each disturbance. Where the exact year is known the letter “a”, for annum, will follow it (*e.g.,* polygon label below). Where the year is estimated, the letter “d” for decadal, will follow it.

Example of a detailed polygon label showing the disturbance descriptors

45% - 6 wS_{10} - P4 - 1981a
SI-4-1980a
CO-5-1978a

Between 76% and 94% of the area was silviculturally treated (SI) in 1980

>95% of the area was harvested (CO) in 1978

6.7 Land-Use Categories

These features reflect human activities and are considered permanent. Land-use features will not receive vegetation interpretation, ecosite description, topography class, soil characteristic, nor soil moisture regime.

6.7.1 Land-Use Clearings

Land-use clearings typically occur as polygons. Selected land-use clearings and their respective code are listed in Table 12.

Table 12. Land-use clearings and their designation.

Feature	Feature Code
Agriculture and pasture	ALA
Populated area (*e.g.,* cities, towns)	POP
Recreation area	REC
Peat extraction	PEX
Gravel pit	GPI
Borrow pit	BPI
Mine site	MIS
Active sawmill site	ASA
Non-active sawmill site	NSA
Other industrial site	OIS
Other unspecified site	OUS
Air facility site	AFS
Cemetery	CEM
Wellhead	WEH
Tower site	TOW

6.7.2 Transportation Features

Roads and other transportation corridor features will be delineated and classified as shown in Table 13. Road, railway, and other corridors will form polygon boundaries where the width (including right-of-way) exceeds 15 m or the polygon attributes on either side of the feature are different.

Table 13. Transportation features and their respective codes.

Feature	Feature code
Roadway corridor	RWC
Railway corridor	RRC
Transmission line corridor	TLC
Pipeline corridor	PLC
Multipurpose or other corridor	MPC

7.0 Polygon Label Guidelines

Labelling of polygons can be according to the needs of the specific user. Where a complete set of attributes is required, they will listed in the polygon as described below or fit into the stand attribute listing adjacent to the map coverage. The convention for the ordering of all attributes will be as follows:

Polygon # - Ecosite #
tree layer 1 (canopy cover%-height-species composition-canopy pattern-year of origin)
tree layer 2 (canopy cover%-height-species composition-canopy pattern-year of origin)
tree layer 3 (canopy cover%-height-species composition-canopy pattern-year of origin)
shrub layer (canopy cover%-species composition)
herb layer (canopy cover%-species composition)
non-vegetated surface layer (% coverage)
topographic class-soil moisture regime
disturbance modifier #1-extent-year
disturbance modifier#2 -extent-year
disturbance modifier#3 -extent-year

Forested Polygon Label Example:

109 - ES62
76% - 20 - $tA_4bP_2wS_4$ - P5 - 1930d
10% - 12 - wS_8bF_2- P2 - 1950d
20% - Ts_{10}
5% RK
H-VF
CO-1-1998a
WI-1-1990d
IN-1-1980d

In the example:

It is polygon **109** and the ecosite is **ES62** (fictional ecosite label)
The overstory (first) canopy covers **76**% of the polygon
The tA is **20** m tall and the bP and wS are within 3 m of 20 m.
The overstory canopy is **40**% **tA** , 20% **bP** and 40% **wS**.
The overstory canopy pattern is **P5** - continuous with openings common.
The overstory originated in or about the **1930 d**ecade.
The second canopy covers **10** % of the polygon.
The wS is **12** m tall and the bF is within 3 m of this height.
The second canopy is **80**% **wS** and **20**% **bF**.
The second canopy pattern is **P3** - few patches of stems.
The second canopy originated in or about the **1950 d**ecade.
There is a **20**% canopy of tall shrub layer (**Ts**), exact species undetermined.
Beneath the canopy layers is a 5% coverage of exposed rock.
The site has hilly topography (**H**), and the moisture regime is very fresh (**VF**)
The stand was partially (1-25%) cut (**CO**) in **1998.**
Windthrow (**WI**) affected 1-25% of the stand (**1**), and occurred around **1990.**
Insect infestation (**IN**) affected 1-25% of the stand (**1**), and is presumed to have started around **1980.**

Appendix I - Aerial Photograph Specification Guidelines

Aerial Photographs

a) Aerial photographs of the survey area shall be taken at a scale ratio of one-centimetre equals fifteen thousand centimetres (*i.e*., 1:15,000).
b) Aerial Photographs of the survey area shall be taken using a standard wide-angle (152.0 millimetre) lens and black and white infrared film (Kodak Infrared Aerographic film 2424) modified by a Kodak Wratten No. 12 or an equivalent approved filter.
c) The camera(s) used shall conform to specifications set forth in the "Specifications for Aerial Survey Photography 1998" and shall be equipped with a forward motion image compensator (FMC). The camera shall be a Wild RC-30 - UAG 1 5/4-S or equivalent.
d) The camera(s) used shall have been calibrated by the National Research Council or equivalent agency within 12 months of the camera being used.
e) The "Specifications for Aerial Survey Photography 1998" shall be the standard which guides the acquisition of aerial photography insofar as those specifications are not inconsistent with the terms of these specifications.
f) Aerial photographs shall be of such clarity and definition as are satisfactory for the determination and delineation of forest species, types and topography.
g) The angle of the sun shall not be less than 30 degrees above the horizon; hot spots shall not be accepted. It is recommended that flying not occur between 1130 hrs and 1300 hrs.
h) Photography will be taken under conditions of minimum haze or smoke that would deteriorate photo quality.
i) The actual true altitude shall be within ±3% of the required true altitude to produce a photograph scale of one centimetre equals 15,000 centimetres (1:15,000).
j) The flight lines will have a lateral overlap of 30%, ± 5% and a forward overlap of 60%, ± 5%
k) Aerial photographs will normally be taken after full leaf flush and before mid-August.
l) A copy of the sensitometer calibration report as prepared by the verification laboratory will be provided.
m) A sensitometer exposure at each end of the roll will be generated.
n) Each negative exposure shall be such that, within a 10-centimetre radius of the fiducial centre, the minimum net density is not below 0.2 or over 0.5. Nowhere on the image shall the density be less than 0.1 above base plus fog. The maximum density on the negative shall not exceed 2.0 above

base plus fog (this replaces ICAS Specification 28) Density Requirements - Monochrome and Colour Films.)

o) An average gradient for negative exposure shall be chosen so that the negative density range is as close to 1.2 as possible. If the density range on a roll of negatives is less than 1.0 and its average gradient is less than 1.3 or if the density range on the roll of negatives is over 1.4 and its average gradient is over 1.0 then it may be assessed that roll of negatives are unsatisfactory (the replaces ICAS Specification 29) Assessment of Exposure and Processing - Monochrome Films).
p) A flight report containing items specified in the "Specifications for Aerial Survey Photography 1998" and the average airspeed and sample exposures of the step wedge will be provided for each roll of negatives.
q) Photographs shall be printed on medium-weight, resin coated, water-resistant based printing paper.
r) A separate index map on polyester film will be prepared for each topographical map sheet at the scale of 1:250,000 for all of the photographs taken.

Annotation of Film Rolls

a) Each negative of an air film roll shall be correctly and neatly annotated in accordance with the required specification before printing. Annotation shall be done with permanent type ink that will not flake or chip off when dry.
b) The film rolls or portion of film rolls containing survey area film shall be left uncut and be identified on the outside end of the spool by showing roll number. Each processed and annotated film roll shall be sent for storage in a container of the same kind as those with which it was originally supplied. Containers are to be numbered in accordance with the roll contained within. An appropriate and approved letter code followed by 4-digit year number, followed by a three digit sequential number shall identify each roll.
c) Flight line numbers shall start with the appropriate and approved letter code, followed by 4 digits for the year of exposure, and then followed by at least a 3 digit sequential number starting with 001, (or as designated by client) on the flight line maps, and progressing upward in numerical sequence.
d) The flight line numbers shall begin in the north and increase in a southerly direction
e) No two (different) prints can share the same annotation.
f) The annotation of the first negative of each roll of film shall show:
    i) The appropriate and approved letter code,
    ii) Roll number,
    iii) Flight line number,

iv) Print number,
v) Bearing of the line of flight (azimuth),
vi) Flight lines and print numbers contained in the roll,
vii) The date each flight line was exposed,
viii) Type of camera used,
ix) Calibrated focal length of the lens used,
x) Type of filter used,
xi) Altitude above sea level (in metres), and
xii) Type of film.

g) The annotation of the first negative of each succeeding flight line within the roll of negatives shall show:
h) The appropriate and approved letter code,
   ii) Roll number,
   iii) Flight line number,
   iv) Print number,
   v) Bearing of the line of flight (azimuth),
   vi) Print numbers contained in the line, and
   vii) The date that the flight line was exposed.
i) The annotation of all negatives in the flight line excluding the first negative of each flight line shall show:
j) The appropriate and approved letter code,
   ii) Roll number,
   iii) Flight line number, and
   iv) Print number.

Appendix II - Interdepartmental Committee on Air Surveys: Specification for Aerial Survey Photography 1998

THIS DOCUMENT REPRODUCED WITH PERMISSION

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SPECIFICATION FOR AERIAL SURVEY PHOTOGRAPHY 1998 Interdepartmental Committee on Air Surveys (ICAS)

INTRODUCTION

This edition of the ICAS Specification for Aerial Survey Photography introduces several changes from the previous specification. The operational specifications remain essentially unchanged except for the addition of a specification governing the use of Kinematic Global Positioning Systems (GPS) and a specification for the aerotriangulation of aerial photography controlled by GPS.

The “Part 4 Specification”, mentioned in the previous specification, has been renamed “Project Requirements” and is still used to define the specific requirements of an ICAS contract.

A major change has been made in the method used to categorize cameras. In addition to the general specification governing lens requirements, consideration will now be given to the resolving power of the lens as well as the features offered by the camera system such as GPS capabilities, serial data annotation and Forward Motion Compensation (FMC). The new classification system has been devised to evaluate 5 major elements of a camera system, resulting in 6 categories of camera classifications.

CAMERA CLASSIFICATION

The following elements will be evaluated when classifying a camera system:

- the area weighted average spatial frequency (AWASF) derived from the Optical Transfer Function (OTF);
- GPS capabilities – navigation, precise photo center positioning and serial data recording and annotation;
- the presence of a FMC system;
- the amount of radial and tangential distortion;
- the amount of image illumination.

The following is a list of the 6 camera classifications available. A camera system must conform to all the characteristics within a particular classification to meet that classification.

CLASS 1:

- AWASF 60 +;
- GPS interface;
- serial data annotation;
- forward motion compensation;
- radial and tangential distortion < 5 µm;
- 50% image illumination.

CLASS 2:

- AWASF 50 to 59;
- GPS interface;
- serial data annotation;
- forward motion compensation;
- radial and tangential distortion < 5 µm;
- 50% image illumination.

CLASS 3:

- AWASF 30 to 49;
- forward motion compensation;
- radial and tangential distortion < 5 µm;
- 50% image illumination.

CLASS 4:

- AWASF 30 to 49;
- radial and tangential distortion < 5 µm;
- 50% image illumination.

CLASS 5:

- AWASF less than 30;
- radial and tangential distortion > 5 µm.

CLASS 6:

- AWASF less than 30.

PHOTOGRAPHY SPECIFICATIONS

In addition to the specifications detailed in the *Project Requirements* of an ICAS contract, the following general specifications must be complied with:
An asterisk (*) signifies that operational aspects of the specification are covered in greater detail in the *ICAS Manual of Procedures*.

1. PHOTOGRAPHIC CONDITIONS

- Photography shall be taken under conditions of minimum haze;
- Solar altitude shall be at least 20º or as specified;
- Cloud or cloud shadow shall not be present on the photography;
- Skies shall be clear unless specified to the contrary.

2. TRUE ALTITUDE*

The altitude specified in the *Project Requirements* is the true altitude, in feet, above mean sea level.
The following methods of tabulating true altitude shall be accepted by ICAS:

- The traditional method of manually applying corrections for air temperature and altimeter instrument error in the determination of the indicated height to fly. Form ICAS-2B provides a pro forma for these computations.
- Computer assisted methods using flight management systems or true air data computers.
- Results derived from Global Positioning Systems shall be accepted with the proviso that an explanation of the method used to derive mean sea level height from the ellipsoidal height is submitted with ICAS Form 2B.

The true altitude shall not deviate by more than ±(1%H+200') from that specified in the *Project Requirements*. The true altitude shall be verified by measuring the scale over an area with the datum specified in the *Project Requirements*.

3. CALIBRATED ALTIMETER

The altimeter used to determine true altitude shall be calibrated every two years in compliance with Transport Canada, Air Navigation Order "Altimeter and Altimeter Static Pressure System" (Series II No. 15).

4. CAMERA OPERATING TEMPERATURE

The camera shall be maintained at a temperature of 20ºC ± 2ºC.

5. CAMERA PORT

The camera shall be mounted behind a port glass meeting Specification 60.

6. HUMIDITY CONTROL

If the camera compartment is not maintained at 58% ± 2% relative humidity, additional exposures immediately prior to the start of the flight line shall be taken as tabled below:

Time since last exposure	Additional exposures
less than 30 minutes	4
30 minutes or longer	8

Failure to observe the above precaution can result in an anomalous colour balance for colour infrared film and dimensional inconsistency in mapping photography.

7. FLIGHT REPORTS*

Flight report forms ICAS-2 and ICAS-2B shall be completed for each roll of photography submitted.
If true altitude is derived from GPS, form ICAS-2B shall be submitted with the required true altitude and the listed indicated height to fly.

8. UNIVERSAL COORDINATED TIME (UTC)

Universal Coordinated Time (UTC) shall be used in the recording of time on the film report and for the camera data panel clock.

9. IMAGE MOTION*

Image motion due to forward motion and angular vibration shall not exceed 20 micrometres in all submitted photography. The project requirements may specify that full forward image motion compensation be set.

10. FLIGHT LINES*

Flight lines will normally be spaced for 30% lateral overlap. In areas of mountainous terrain, the datum chosen shall be such that the minimum lateral overlap shall not fall below 20%.

In certain instances of extreme terrain relief, the ICAS will add intermediate flight lines in order to maintain a minimum of 20% lateral overlap at points of minimum terrain clearance.

It is incumbent upon the contractor to check the flight plan provided to ensure that the lateral overlap requirements of the project specification can be met.

11. COVERAGE

The photographic flight shall extend far enough beyond the borders of the specified area to ensure full stereoscopic coverage of the entire area included within the border.

12. FLIGHT DEVIATIONS*

The following tolerances are permissible:

course change:	± 3 º	combined limit
drift:	± 3º	of 5º of apparent crab
verticality:	± 2.5º	
forward overlap:	60% ± 4%	or as specified
lateral overlap:	30% ± 15%	or as specified
true altitude:	± (3%H + 200')	or as specified

13. FORWARD OVERLAP - MOUNTAINOUS TERRAIN*

When the terrain relief above mean ground level exceeds 5% of the flying height, the forward overlap shall be maintained such that the overlap over the highest ground does not fall below 55% or above 58% unless otherwise permitted in the *Project Requirements*.

14. FLIGHT JOINS

Photo lines should be flown in a continuous unbroken strip. Joined lines may be accepted in long lines providing the two parts of the line overlap at the break by at least two photographs. Joined lines with less than 5 photographs in each section will not be accepted. The line should be re-flown.

15. REJECTION OF PHOTOGRAPHY IN MID-LINE

A break in the sequence of photographs caused by rejection of photography not meeting the specifications may be cause for rejection of the entire line if the remaining segments are short.

16. PHOTOGRAMMETRIC QUALITY*

The photography shall not have residual y-parallax over 10 microns and shall not contain any areas of localized lack-of-flatness due to dirt on the platen or vacuum-failure.
Spot checks will be made throughout the roll and any evidence of failure to meet this specification can result in rejection of the entire roll.

17. FIDUCIAL DOTS

The fiducial dots shall be present in all photography taken where topographic mapping photography has been specified. Failure to record these dots can result in rejection of the roll.

18. CLOCK

The clock shall be set and operating on Universal Coordinated Time (UTC). Failure of operation or failure of the illumination system causing lack of legibility on the negative can result in rejection of the roll if the user deems this information essential.

19. FILM STORAGE AND CONDITIONING*

Unexposed films shall be stored in their sealed containers at temperatures not higher than the following:

	2 weeks	3-4 months	longer
monochrome	20ºC	12ºC	-20ºC
Colour	20ºC	12ºC	-20ºC
Colour IR	20ºC	2ºC	-20ºC
monochrome IR	20ºC	2ºC	-20ºC

Films stored at low temperatures shall be conditioned to ambient temperature before opening the container, loading the camera or processing. Typical conditioning time from –20ºC to 20ºC is 8 hours.
Exposed film shall not be subjected to temperatures exceeding 20ºC.

20. SENSITOMETRIC EXPOSURE*

At least one sensitometric exposure shall be made on each roll of film prior to processing. The exposure shall be made on unexposed film, which will not be subject to anomalous development effects. Ideally, sensitometric exposures should be exposed at each end of the roll.

The sensitometer used shall provide for the determination of average gradient to an accuracy of 0.05% and should provide for the determination of aerial film speed. Determination of average gradients shall be in accordance with the methods defined in CSA Z7.3.2.1 “Sensitometry of Monochrome Aerial Films”.

21. USE OF FILTERS ON SENSITOMETRIC EXPOSURES*

Sensitometric exposures shall be printed with <u>no</u> auxiliary filter in the sensitometer, except for the particular case of <u>colour infrared film</u> when a Wratten #12 or equivalent filter shall be used in the sensitometer.

22. SENSITOMETRIC TESTING - COLOUR INFRARED*

The colour balance of colour infrared film shall be established by processing and evaluating a sensitometric exposure prior to commencing work.
It is desirable that the infrared balance be adjusted by filtration during exposure in accordance with the methods outlined in the ICAS publication *Standardization Techniques for Aerial Colour Infrared Film.*

23. SENSITOMETER – CALIBRATION

The sensitometer shall have a valid calibration. The sensitometer shall be calibrated or its calibration verified at intervals of one year. Sensitometers designed and built by the National Research Council shall be calibrated by NRC. Sensitometers other than the NRC-designed type can be calibrated by the ICAS by comparison with a NRC-designed type. The ICAS shall charge the contractor for the developing of the film and the calibration service.

24. DENSITOMETER

The densitometer used in the measurement of the sensitometric exposures and film densities shall read diffuse transmission density as defined in CSA Z 7.2-1973 “Specifications for Diffuse Transmission Density” for CSA Type VI-b.

25. PROCESSING*

All film shall be processed in a continuous processing machine.
Processing and storage shall not cause differences in dimensional change greater than 0.02% ± 15 micrometres.
Average gradient shall not vary by more than 0.05 from start to end of the roll.

26. PERMANENCY*

The permanency of the photographic image shall be the best that can be obtained by normal processing and thorough washing.
Films will be tested for residual hypo content using Kodak Hypo Test solution HT-2. A visual match with colour patch-2 of the Kodak Hypo Estimator indicates the limit of acceptable residual hypo.

27. EXPOSURE AND PROCESSING - MONOCHROME AND COLOUR FILMS

The exposure of aerial films shall ensure recording of significant shadow and highlight details within the latitude of the film when processed in accordance with the manufacturer's recommendations.

28. DENSITY REQUIREMENTS - MONOCHROME AND COLOUR FILMS *

For monochrome and colour negative films, the exposure shall be such that, within a 10 cm radius of the fiducial centre, the minimum net density is not below 0.2 or over 0.6. Nowhere on the negative shall the density be less than 0.1 above base plus fog.
Except for images of extremely bright spots, such as specular reflections of the sun, the maximum net density on the negative shall not exceed 2.0 above plus fog.
For colour positive films, the exposure shall be such that, within a 10 cm radius of the fiducial centre, the minimum net density is not below 0.2 or above 0.4. Nowhere on the positive shall the density be less than 0.2. Densities should be read on land detail at least 5 mm in extent.

Film type	Minimum net density within 10 cm radius of fiducial centre	Anywhere on negative		Maximum net density
monochrome	≥ 0.2 and ≤ 0.6	not less than 0.1	above base + fog	not to exceed 2.0
Colour negative	≥ 0.2 and ≤ 0.6	not less than 0.1	above base + fog	not to exceed 2.0
Colour positive	≥ 0.2 and ≤ 0.4	not less than 0.2		

29. ASSESSMENT OF EXPOSURE AND PROCESSING - MONOCHROME FILMS*

An average gradient of development shall be chosen so that the negative density range is as close to 1.0 as possible.
In achieving the aim density range of 1.0, the contractor is expected to use low-contrast processing for high-brightness range terrain and high-contrast processing for low-brightness range terrain.
If the density range on a roll is less than 0.7 and its average gradient is less than 1.3
or
if the density range on the roll is over 1.4 and its average gradient is over 1.0
then
it may be assessed that the contractor has not met the requirements of this specification.

30. ANNOTATION*

Each negative submitted as part of the contract commitment shall be annotated in sequence, using a roll number supplied by the ICAS. Roll number annotation is to be placed in the lower left corner when the start (physical and calendar) of the roll is at the right hand of the annotation table and the emulsion is down. (See section 58 Film Transport Direction). The nominal scale of the photography shall be centered along the lower edge of the photograph and the date shall be annotated along the lower right side of the photograph.

Annotation standards are defined in the *ICAS Manual of Procedures*.

31. SPOOLING OF NEGATIVES

Rolls of survey film shall normally be left uncut and submitted for storage on a spool of the same kind as that on which it was originally supplied. Cans and spools from 500' rolls will not be accepted.

32. LEADERS, TRAILERS, SPLICES

Each roll of air survey film shall be delivered with at least two metres of leader and trailer containing no annotated negatives.
A roll shall be considered unique when it has no splice. Whenever a roll is cut to remove non-ICAS photography, the parts shall be considered as separate units. If both parts have been taken with the same camera, the roll may be spliced together again providing at least 0.5 m of unannotated film is retained on each side of the splice.
Splices shall be a butt join using 3M no. 810 transparent tape (or equivalent) applied to both sides of the film.

33. PRINTS*

As a minimum, one print of each annotated negative shall be made using an automatic dodging printer, unless otherwise specified in the project requirements.
The printer shall meet CSA Specifications Z 7.2(ANSI PH 3.8), Z 7.2.1 and Z 7.2.2.

34. INDEXES*

Indexes are to be supplied on NRCan topographic maps and prepared in accordance with NAPL requirements as defined in the *ICAS Manual of Procedures* or as specified in the project requirements.

35. DELIVERY ITEMS / ROLL*

1. Annotated aerial negatives;
2. Prints and diapositives as specified;
3. ICAS-2 Air Photography report (4 copies);
4. ICAS-2B altitude computation or method used to derive mean sea level;
5. Flight indexes and all copies of same;
6. GPS reports and/or data as specified;
7. Packing slip listing:

ICAS contract number;	Area, by roll and negative number;
Line number and line kilometres;	Number of sets of prints;
Forms and indexes supplied;	Status of delivery (Final/Progressive).

CAMERA SPECIFICATIONS

36. FOCAL LENGTH

The focal length shall fall within one of the following classes:

super-wide angle:	87.5 ± 3.5 mm
wide-angle:	152.0 ± 3.0 mm
intermediate angle:	210.0 ± 5.0 mm
normal angle:	305.0 ± 3.0 mm
long focus:	610 mm (tolerance is not critical)

37. PICTURE FORMAT SIZE

The nominal picture format size shall be 23 cm x 23 cm.
Fiducial marks or other recording devices situated within the format shall not reduce the semi-field angle to less than 42.6º (wide angle) or intrude into the side of the picture by more than 7 mm.

38. OPTICAL UNIT

The camera shall have a rigid mechanical structure which holds the lens, fiducial marks, and the parts defining the focal plane.
This structure shall be supported in use in such a manner that strains cannot be transmitted to it from the supporting body or mount (a kinematic design).

39. FIDUCIAL MARKS - GENERAL

The fiducial marks shall produce precise registrations on every negative and shall provide a record of two fixed mutually perpendicular calibrated camera distances.
The lines joining opposite fiducial marks shall intersect at 90º ± 1".

40. FIDUCIAL MARKS - TOPOGRAPHIC MAPPING

In addition to the requirements under Fiducial Marks – General, the fiducial marks shall contain a central dot 80 μm ± 30 μm in diameter.

41. FIDUCIAL CENTRE - GENERAL

The lines joining opposite fiducial marks shall intersect at the fiducial centre.
Neither the principal point of autocollimation nor the centre of best symmetry shall be further from the fiducial centre than 0.10 mm.

42. FIDUCIAL CENTRE - TOPOGRAPHIC MAPPING

In addition to the requirements under Fiducial Centre – General, neither the principal point of autocollimation nor the centre of best symmetry shall be further from the fiducial centre than 0.05 mm.

43. SHUTTER

The shutter shall be a between-the-lens type. The shutter speeds, both total and effective, shall be known by the contractor.

44. RESOLUTION

The resolution of the lens type shall be in accordance with the possibilities of current design knowledge. The resolution of an individual camera shall be such that its average resolving power is not less than 85% of the mean value for its type.

45. CALIBRATED FOCAL LENGTH

The calibrated focal length shall be chosen so as to minimize the departure of the measured radial distortion from the lens reference curve for the lens type, or from zero distortion if no reference curve for the particular lens exists (reference Appendix 1a: LENS DISTORTION REFERENCE CURVE).

46. RADIAL AND TANGENTIAL DISTORTION

The measured radial and tangential distortion shall not exceed the limits set below. Tolerances (mm) are given for measured radial and tangential distortion for

a) super-wide and wide-angle topographic mapping cameras
b) other cameras (i.e. reconnaissance systems).

FIELD ANGLE		up to 42.2º	43.5º to 53.5º	more than 53.5º
Departure of average radial	(a)	0.005	0.010	0.015
distortion from reference	(b)	0.010	0.020	0.040
Asymmetry about principal	(a)	0.015	0.030	0.040
point of auto-collimation	(b)	0.035	0.070	0.140
Asymmetry about principal	(a)	0.005	0.010	0.020
point of best symmetry	(b)	0.010	0.020	0.040
Relative tangential	(a)	0.005	0.010	0.020
distortion	(b)	0.010	0.020	0.040

47. RADIAL DISTORTION LIMITATIONS WHEN LENS DISTORTION AND EARTH CURVATURE CORRECTION PLATES ARE TO BE USED IN MAPPING

The radial distortion reference curves for Wild Aviogon, Universal Aviogon and Sag II lenses match correction capabilities available to the Mapping Services Branch, Natural Resources Canada (NRCan).

These lenses, when used to obtain photography for NRCan, must conform to their reference curves within the tolerances given below. Other lenses must meet the tolerances given with respect to zero distortion.

	Lens	Field Angle Tolerance (mm)
Aviogon	up to 42.2º	0.005
Universal Aviogon	beyond 42.2º to 50.6º	0.010
SAG II	beyond 50.6º	0.015
others	up to 50.	0.010
(zero reference)	beyond 50.6º	0.015

48. FOCUS

The camera focus setting shall be that which gives the best definition as measured by the National Research Council.

In the case of long-focus lenses it may be desirable to refocus the lens for the altitude being used when the operating altitude is less than

$$H = 0.33 * (f^2)/N$$

where: f = focal length (mm)
N = aperture setting (f-stop)
H = altitude above ground in feet.

49. STRAY LIGHT CONTROL

All lens surfaces shall have anti-reflection coatings. Filter surfaces should have anti-reflection coatings.

If a graded transmission filter is used, the side with the higher reflectivity shall be mounted toward the camera lens.

50. VEILING GLARE

Veiling glare shall not exceed 10%.

51. IMAGE PLANE ILLUMINATION – MONOCHROME PHOTOGRAPHY

The lowest image illumination shall not be less than 30% of the highest illumination found up to 140 mm off-axis for wide-angle lenses or to 125 mm off-axis for super-wide-angle lenses.

52. IMAGE PLANE ILLUMINATION – COLOUR PHOTOGRAPHY

The lowest image illumination up to 140 mm off-axis shall not be less than 50% of the highest illumination found. Present super-wide-angle lenses do not meet this requirement and are not suitable for use with colour films.

It is preferable that for all colour photography, the lowest image illumination should not be less than 60% of the maximum.

53. CHROMATIC LENS CORRECTION - INFRARED PHOTOGRAPHY

The camera lens shall be colour corrected in the range 400 to 900 nm. of the spectrum. (Lens type examples: Universal Aviogon and Pleogon A).

54. FLATNESS OF FILM LOCATING SURFACES

The flatness of film locating surfaces shall be within 0.008 mm.

55. CAMERA DATA BLOCK

The camera shall have data blocks containing the lens number, nominal focal length, exposure counter and a clock with either a digital read-out or a sweep second hand. The illumination of the instruments shall be such that the readings are legible on the film. Forward-motion compensation cameras should have a legible indication of the compensation switch being on or off.
The limit of compensation should be indicated on the data blocks or present in the serial data annotation.

56. CAMERA VACUUM

A vacuum gauge or other device warning of vacuum failure shall be connected as closely as possible to the platen. It is preferable that the camera be automatically rendered inoperable if the vacuum system fails.

57. CAMERA MOUNT

The camera mount should provide sufficient vibration insulation so that the camera vibration need never be a limiting factor in the selection of shutter speeds.

58. FILM TRANSPORT DIRECTION

The camera shall be mounted so that the film transport over the focal plane is in the direction of flight.

59. CAMERA CYCLING

The camera cycling shall be such that the film advance occurs immediately after camera exposure.

60. CAMERA PORT GLASS

The camera port glass shall not cause a deviation of collimated light at normal incidence by more than 10 seconds or a change in deviation by more than 2 seconds over the area of the glass.

61. FILMS AND SPOOLS

The film and spools used shall comply with CSA Z 7.3.1.5 Table 6 defining the dimensions for films, leaders, trailers, spools and spindle holes.

62. FILTERS

Except for gelatine filters used in a glass sandwich filter, all filters used in front of the lens shall be made of glass.
The deviation produced by the filter for collimated light at normal incidence shall not exceed 10 seconds and the change of deviation shall not exceed 2 seconds over the area of the filter.

63. FILTERS - TOPOGRAPHIC MAPPING

For black and white photography, the camera shall be calibrated with the filter with which it is to be used.
Provision shall be made to ensure that a single orientation for the filter on the camera can be easily and reliably maintained.

64. FILTERS - COLOUR PHOTOGRAPHY

Filters used to modify the colour balance or compensate for altitude when colour infrared film is used may be gelatine filters mounted in a glass sandwich filter holder in front of the lens or may be mounted inside the camera body in a frame designed to hold them flat.

65. ANTI-VIGNETTING FILTER

The image illumination requirements may be met by the use of a filter with a graded transmission.

66. CAMERA CALIBRATION

All cameras used on ICAS contracts shall be calibrated by the National Research Council prior to use. The testing methods used shall in general, accord with the "Recommended Procedures for Calibrating Photogrammetric Cameras and Related Optical Tests" of the International Society for Photogrammetry, Commission I.
The National Research Council shall have the right to refuse to undertake calibration if the camera is not operationally sound. The charges for calibration services are set and the rates published by the National Research Council.

67. CAMERA CALIBRATION REPORT

All cameras used for photography under these specifications shall have a valid calibration report. The National Research Council shall send one copy of each calibration report to the owner of the equipment and one copy to the National Air Photo Library. The owner of the equipment may make copies of the report but such copies shall be of the entire report and shall be reproduced by duplication, not re-typing. The validity of a calibration report for a camera shall be for two calendar years following the date of calibration.
A camera calibration report is invalid when:

- the calibration date has exceeded two calendar years;

- the camera has had a major overhaul that could affect the properties of the optical unit or the platen;
- the camera or platen has been subject to damage, disassembly or alteration.

A sample camera calibration report that employs the SMAC technique is included in Appendix 2a.

68. CAMERA CALIBRATION PARAMETERS (ELEMENTS EVALUATED IN A CAMERA CALIBRATION

The camera calibration shall include the following:

- measurement of principal point of auto-collimation with respect to the fiducial coordinate system;
- measurement of principal point of best symmetry with respect to the fiducial coordinate system;
- determination of lens distortion characteristics, both radial and tangential, without a filter or with a filter of the contractor's choice - if the camera is to be used for topographic mapping, the calibration shall be done with the filter to be used for black and white photography;
- determination of the calibrated focal length;
- determination of the flatness of film locating surfaces;
- determination of focal plane illumination;
- determination of total and effective shutter speeds;
- check of focus;
- measurement of fiducial distances and determination of fiducial mark locations in X and Y coordinates;
- testing of the filter(s) for deviation and change of deviation;
- determination of film plane illumination for all glass filters to be used for colour photography (clear AV, sandwich, 425 nm, 525 nm, Zeiss B, D, etc.);
- determination of AWASF;
- determination of camera classification - this shall be noted prominently on the first page of the calibration report.

69. ICAS PREROGATIVE

The ICAS reserves the right, at the contractor's expense, to request calibration, servicing or a flight test of a camera system prior to use on a contract.

AIRBORNE GPS OPERATIONS

70. ACCURACY REQUIREMENTS

The perspective centres shall be positioned with an accuracy that will meet the aerotriangulation requirements. The aerotriangulation accuracy can be evaluated using check points whose values root means square (RMS) of coordinate differences are **F**xy # 30 µm and **F**z # 30 µm at photo scale.

71. GPS ANTENNAS

Aircraft GPS antenna(s) shall be the dual-frequency, microstrip type with a preamplifier. The preamplifier shall match the manufacturer's specifications for the receiver antenna input.
Monitor site GPS antennas shall be dual frequency and should be the same make and model as the antenna(s) used on the aircraft.

72. GPS RECEIVERS

Dual-frequency receivers with 8 or more independent or parallel (non-sequenced channels) shall be used.
Receivers shall be capable of tracking the L1 C/A code and the L1/L2 P code when Anti-Spoofing (AS) is off, and producing a high quality code and full wavelength L1 and L2 carrier phase measurements when AS is on.
Receivers of the same make and model should be used in the aircraft and at monitor sites.

73. NUMBER AND LOCATION OF GPS RECEIVERS

At least one GPS antenna and receiver shall be used in the aircraft. It is preferable to have the antenna located directly above the camera's perspective centre. The use of more than one system is encouraged to enhance the integrity of the position determination, as well as to serve as a back up in case of equipment malfunction.
At least two GPS receivers shall be set up simultaneously as monitor sites on points with accurately known three-dimensional coordinates (see Section 76). These monitor sites are to be located at opposite ends of the flight area.

74. OFFSET MEASUREMENTS BETWEEN THE GPS ANTENNA PHASE CENTRE AND THE CAMERA'S PERSPECTIVE CENTRE (PC):

The contractor shall explain and illustrate, in a sketch or photograph, the location of the antenna(s) and camera on the aircraft. The contractor shall provide the measurements between the camera's perspective centre and the GPS antenna phase centre, along with accuracy estimates. The procedures and instrumentation used for making the offset measurements shall also be provided.
The contractor shall provide full details on how attitude changes between the camera's perspective centre and the antenna phase centre are handled in the GPS processing, aerotriangulation or both. This shall include discussion on whether the camera is "locked-down" or uses a gyro-stabilized mount.

75. INTERPOLATION OF GPS POSITIONS TO TIME OF EXPOSURE

To minimize interpolation errors, data collection shall be at a frequency of at least 1 Hz and preferably 2 Hz.

The type and accuracy of the timing interface between the camera and GPS receiver shall be stated.
The method used to interpolate from the GPS solutions, the position of the camera's PC at the time of exposure, shall be explained.

76. MONITOR SITES

The contractor is responsible for establishing monitor sites and carrying out any surveys required to provide accurate coordinates for the monitor sites. If surveys are carried out to establish monitor site coordinates, data and reporting on the survey shall be included with the deliverables.

77. GROUND CONTROL

The contractor is responsible for any ground control used to supplement airborne GPS aerotriangulation. If surveys are carried out to establish ground control, data and reporting on the survey shall be included with the deliverables.

78. CHECK POINTS

ICAS reserves the right to establish check points or have check points established by the contractor.

79. GPS FIELD LOGS

Field logs shall be completed for each receiver, for each session or flight of GPS data collection. As a minimum, the following information shall be included on the field logs:

a) date of observations;
b) data collection start and end times;
c) station identification (for ground stations);
d) model and serial numbers for the GPS receiver and antenna;
e) version of firmware for the GPS receiver;
f) height of the antenna phase centre above the marker, accompanied by a sketch showing all measurements taken to derive the height;
g) the file name for the collected GPS data;
h) data collection rate and receiver mask angle;
i) all problems or unusual behaviour with equipment or satellite tracking.

80. DATA BACK-UPS

All raw GPS data shall be backed up and duplicate copies of field logs shall be made. The contractor shall store a copy of the data for one year following the contract completion date.

81. GPS SOLUTIONS FROM TWO MONITOR STATIONS

The aircraft trajectory shall be obtained from independent solutions relative to the two land-based monitor sites. The difference between the two trajectories shall be plotted and analyzed. Any trends or biases between the two data sets shall be explained. If problems that jeopardize the integrity of the computed positions are evident, the affected lines shall be reflown. The contractor shall determine a single set of positions for each camera station from the two independent solutions, and explain how this was done to provide the best position estimates.

82. ACCURACY ESTIMATES

The contractor shall provide accuracy estimates of the coordinates for the perspective centres along with a clear explanation as to how these accuracy estimates were derived. The estimates provided with the GPS solutions shall not be used as the sole source of accuracy information.

The contractor shall provide accuracy estimates for any coordinates determined for monitor or ground control sites and shall explain the source of these accuracy estimates.

83. FINAL COORDINATES

Final coordinates for camera perspective centres shall be provided in UTM northings and eastings (NAD83-based) and orthometric (mean sea level) heights. The contractor shall state the geoid model used to derive orthometric heights from GPS relative to the Canadian Geodetic Vertical Datum 1928 (CGVD28).

GPS DELIVERABLES

84. GPS DATA FILES

The contractor shall provide all collected GPS data in both native (i.e. receiver-specific format) and RINEX (Receiver-Independent Exchange) format, version 2 or later. This raw data shall be delivered on CD ROM or 100 mb zip disk.

If a static GPS survey is used to establish ground control or monitor sites, then coordinate or coordinate difference observations in GHOST or GEOLAB input format, with associated variance covariance matrices for each session, and the resulting adjusted 3D coordinates and associated full covariance matrix from the minimally constrained adjustment, shall be provided.

The contractor shall provide in digital format, the aircraft trajectories computed from the two monitor sites, along with accuracy estimates. This data shall be delivered on CD ROM or 100 mb zip disk.

The contractor shall provide, in digital format, final coordinates for all perspective centres in UTM northings and eastings based on NAD83 and orthometric heights (mean sea level heights), relative to the Canadian Geodetic Vertical Datum (CGVD28). This data shall be delivered on CD ROM or 100 mb zip disk.

85. HARD COPIES OF DATA

Field logs for all GPS observations shall be submitted. Digital format will be accepted if it is the format used for fixed observations.

86. MAP

The report submitted by the contractor shall be accompanied by a map or map overlay showing the monitor sites occupied, all flight lines, and all ground control used.

87. FIELD OPERATION DETAILS

The contractor shall provide a clear description of the survey procedures used in the field. Procedures for kinematic GPS surveys to position the camera's perspective centre as well as static GPS surveys to establish ground control and monitor sites shall be addressed. This includes but is not limited to:

- a summary of the equipment used including serial numbers, and a brief description of their characteristics and principles of operations;
- a summary table indicating for each flight, the date, the start and end time of GPS data collection the line numbers with their start and end times, and the file names for the GPS data collected in the aircraft. In addition, the table should show for each monitor site, the station name, the start and end time of GPS data collection and the data file names;
- a summary table for static GPS observations indicating for each session, the date, the session number, the stations occupied and the start and end time of observations for each station.

88. OFFSET MEASUREMENTS

Details on offset measurements between the GPS antenna phase centre and the camera's perspective centre shall be provided, as described in Section 74. This includes full details on how coordinates of the antenna phase centre are transferred to the camera perspective centres to estimate their coordinates and their accuracies, to be used in the aerotriangulation adjustment.

Details on the interpolation of GPS positions to time of exposure shall be provided, as described in Section 75.

89. PROCESSING DETAILS

The contractor shall provide a clear description of procedures used for data processing of both static and airborne data. This includes but is not limited to:

a) software (name, version number and date) used in the data processing along with a description of the basic underlying principles on how the software determined accurate GPS positions;
b) parameters adopted in the processing;
c) ephemeris used (broadcast or precise);
d) number of satellites used and the satellite geometry
e) details about any problems encountered in the processing and how they were overcome;
f) software (name, version and date) used for coordinate transformations;

g) the geoid model used to transform the ellipsoidal heights derived from GPS to orthometric (mean sea level) heights;
h) software used (name, version and date) to convert native GPS receiver data to RINEX format;
i) for any ground control or monitor sites used, a table showing the station name and number, the coordinates used, the datum, the source of the coordinates, coordinate accuracy estimates and the source of the accuracy estimates.

90. ANALYSIS DETAILS

The contractor shall provide:

a) computer listings of results to include processing statistical RMS of solutions, details of ambiguity resolution or other details as applicable, depending on the software used;
b) a comparison of the coordinates of the GPS antenna as processed from the two (or more) monitor sites; as a minimum, the comparison should be in graphical form indicating the differences in each coordinate axis plotted against time;
c) a plot of the residuals from GPS processing against time;
d) any other analysis suitable to the software and techniques employed that shows the accuracy and integrity of the data.

AERIAL TRIANGULATION SPECIFICATIONS FOR AIRBORNE GPS AERIAL PHOTOGRAPHY

91. AERIAL TRIANGULATION PROCEDURES

Unless specified otherwise, the point numbering convention to be used will be the 6 digit coding as specified in the Department of Natural Resources Canada Coding Procedures (July 1982).

Point selection, transfer and marking will be carried out stereoscopically using an instrument equivalent to the Wild PUG-3 in accuracy. The mark shall be approximately 60 μm in diameter and will be cleanly drilled or burned on the emulsion surface.

Point selection, transfer, marking and measurement can be performed on a digital photogrammetric station (DPW) by image matching techniques. The statistics of results and the procedures set shall be provided.

All mensuration will be performed on first-order instruments, including analytical stereoplotters and DPWs, capable of producing precise data for analytical aerial triangulation. The results must be in plate and model coordinates and must include related procedure and accuracy information

i. forming models and strips and
ii. archiving and retrieving plate and model coordinates.

All ground control and check points must be coded and symbolized on the photo. They must also be pugged or targeted on the film positive. A cross-reference list between the field identification and the 6-digit code must be provided.

Two (2) adjustments must be submitted. The first with checkpoints weighted 0.0 and the second with check points weighted 1.0.
If there are adjacent adjustments, block ties are required as check points.
Deformation due to earth curvature and atmospheric refraction will be eliminated using earth curvature correction software or by the use of correction plates.
The mapping contractor must ensure that the instruments are properly calibrated before commencing aerotriangulation measurements.

92. HORIZONTAL DATUM AND MAP PROJECTION

Unless specified otherwise, all horizontal control points will be on the NAD83 datum and coordinate values shall be on the 6º Universal Transverse Mercator projection.

93. HORIZONTAL ACCURACY

The adjustment will meet the following statistical standards:
a) Control
The mean square positional error (MSPE) on the location of all horizontal check points used in the adjustment will be smaller than or equal to 20 µm at photo scale.
The MSPE of 90% of the residuals will be smaller than or equal to 30 µm at photo scale.
The single-point observation rejection criteria shall be 48 µm at photo scale at the 99.78% confidence level.
b) Ties
The MSPE of the tie point residuals used will be smaller than or equal to 10 µm at photo scale.
The MSPE of 90% of point residuals shall be less than or equal to 15 µm at photo scale.
The rejection criteria at the 99.78% confidence level shall be 25 µm at photo scale.
c) Checkpoints
The MSPE on the location of all horizontal check points used in the adjustment will be smaller than or equal to 30 µm at photo scale.
The MPSE of 90% of the residuals will be smaller than or equal to 46 µm at photo scale.
The single-point observation rejection criteria shall be 74 µm at photo scale at the 99.78% confidence level.

94. VERTICAL DATUM

Elevations will be above mean sea level datum (CGVD28) as established by the Geodetic Survey of Canada. All vertical control points are to be included in the adjustment.

95. VERTICAL ACCURACY

a) Control
The root mean square error (RMSE) of all vertical control points used will be smaller than or equal to 20 µm at photo scale.
The RMS of 90% of the residuals will be smaller than or equal to 33 µm at photo scale.

Single-point observation rejection criteria will be 60 µm at photo scale at the 99.73% confidence level.

b) Ties

The RMSE of the point residuals used will be smaller than or equal to 10 µm at photo scale.

The RMSE of 90% of the residuals shall be smaller than or equal to 16 µm at photo scale.

Single-point observation rejection criteria shall be 30 µm at photo scale at the 99.73% confidence level.

c) Checkpoints

The RMSE of all vertical check points used will be smaller than or equal to 30 µm at photo scale.

The RMS of 90% of the residuals will be smaller than or equal to 49 µm at photo scale.

Single-point observation rejection criteria shall be 90 µm at photo scale at the 99.73% confidence level.

96. EVALUATION OF AERIAL TRIANGULATION

It is to be noted by the contractor that the evaluation of the adjustment results against the stated standards will not be solely based on the statistical results of the adjustment. The following elements must also be evident in the adjustment.

1. Proper aerial triangulation technique with respect to:
   a) control points;
   b) tie point locations;
   c) use of check points
2. No evidence of a systematic nature to the residuals on either:
   a) control points,
   b) photogrammetric points, or
   c) check points
3. The block remains structurally sound while meeting the rejection criteria.
4. The RMS on the check points must be less than or equal to 30 µm, unweighted, at photo scale.
5. Meet all other specifications as indicated in the contract.

The inspector is responsible for the final interpretation of the specifications and for the final acceptance of the aerial triangulation block adjustment results.

97. INDEX

An index is required in the form of a neat model index showing:

i. photogrammetric models;
ii. horizontal or vertical control;
iii. check point locations;
iv. outline of mapping limits;
v. vector of horizontal control and check point residuals.

The index will be at a scale of 1:50000 for photography at scales of 1:5000 to 1:20000 and at 1:250000 for photography at scales smaller than 1:20000.

98. MATERIALS TO BE SUPPLIED BY THE CONTRACTOR

The mapping contractor shall supply the following materials to ICAS for inspection and archiving:

a) neat model index as described in Section 97;
b) adjustment report;
c) cross reference list of check points and ground control;
d) plate coordinates on diskette; format Patb*
e) independent model coordinates and perspective centres on diskette; format Patm*
f) computer listing of adjustments; one adjustment with check points weighted 0.0 and the second with check points weighted 1.0
g) results of the adjustments on diskette; Spacem, tape4 file and print file, K block adjustment file and bin file
h) contact prints used for aerotriangulation;
i) film positives used for aerotriangulation.

* See sample file on next page:

MENSURATION

Analytical, first order instrument capable of producing precise data. Data to be collected on a computer. Atmospheric refraction and earth curvature will be corrected.

REQUIRED MATERIAL AND SPECIFICATIONS - Deliverables

Raw image coordinate data, Patb format, and file on diskette.

Sample file of Patb

220830	152.703	
224029	98134.0	14127.1
220048	93522.6	105879.2
220028	-2146.7	101120.3
224019	1306.8	208.9
220019	570.0	-85223.4
220029	93489.7	-73749.3
222029	94096.4	-32651.2
220038	95342.3	75088.7
220018	1081.0	69013.4
222019	-2970.3	-45804.7
-99		

Results of relative orientation and strip formation, listing. Specifications 20, 30 and 40 microns for X, Y and Z.

Independent Model data, file on diskette, DOS ASCII - Patm format. Model number and left PC to be coded with line and sequence number of left pass point number.

Sample file of Patm

3324			
330240	500.000	500.000	500.000
330250	588.682	501.983	501.049
334249	502.138	493.704	345.886
332467	513.122	522.982	345.580
336249	504.412	546.626	345.433
330268	484.485	577.341	345.326
330278	511.339	580.961	345.324
330288	591.446	592.832	345.792
335011	586.536	526.078	346.149
334259	590.050	502.826	346.418
320338	589.291	450.025	346.704
320348	593.943	409.933	347.068
320328	496.520	407.970	345.979
320318	502.101	448.742	346.178
336259	587.273	563.037	345.907
-99			

LIST OF ABBREVIATIONS, ACRONYMS and SYMBOLS

ANSI	American National Standards Institute
AS	anti-spoofing
AV	anti-vignetting
AWASF	area-weighted average spatial frequency
C/A code	coarse acquisition code
CGVD	Canadian Geodetic Vertical Datum
CSA	Canadian Standards Association
FMC	forward motion compensation
GPS	global positioning system
H	flying height
Hz	hertz
ICAS	Interdepartmental Committee on Air Surveys
IR	infrared
L1	carrier wave signals of 1575.42 MHz
L2	carrier wave signals of 1227.60 MHz
mm	millimetre
MSPE	mean square positional error
NAD	North American Datum
NAPL	National Air Photo Library
Nm	nanometre
NRC	National Research Council of Canada
NRCan	Natural Resources Canada
OTF	optical transfer function

PC	perspective centre
P code	Precision code
RINEX	Receiver-Independent Exchange
RMS	root mean square
RMSE	root mean square error
SMAC	simultaneous multiframe analytical calibration
USGS	United States Geological Survey
UTC	Universal Coordinated Time
UTM	Universal Transverse Mercator
F	sigma
µm	micrometre (micron)

DEFINITIONS

Anti-spoofing: is the process whereby the P-Code, used for precise positioning, is deliberately altered by the U.S. Dept. of Defence in order to conceal the exact location of a satellite

Apparent crab: the angle between the line joining the mid-points of the sides of the pictures in the direction of flight and the flight path as defined by the fiducial centre of the photos.

Area weighted average resolution: a figure representing the average value of the resolution of the entire image area, usually expressed in line pairs/mm or cycles/mm.

Area-weighted average spatial frequency: refers to the average value of target spacing over the entire image which meets the criterion value for sharp image over the entire scene.

Checkpoint: a targeted point on the ground with known coordinates, that is identifiable on an aerial photograph, which is used to check the accuracy of aerotriangulation based on kinematic GPS positioning

Carrier phase: a radio wave which may be varied from a known reference value by modulation

Datum: a figure (usually in feet) representing the average height of the ground elevations above sea level in an area to be photographed

Ground control: a targeted point on the ground with known coordinates, that is identifiable on an aerial photograph, which is fixed or weighted in the aerotriangulation adjustment.

Image motion: the blurring effect seen on aerial imagery due to the relative movement of the camera with respect to the ground at the time of exposure.

Micrometre: one millionth of a metre or one thousandth of a millimetre.

Modulation: a method of measuring contrast. It is derived by taking the values of the maximum and minimum difference of transmittance, reflectance or luminance of a target and dividing the difference by their sum. This number always falls between 0 and 1.

Modulation transfer function: a representation of the ability of a lens to transfer contrast from an object to a photographic image. This ability is expressed in line pairs/mm. The

contrast recorded on the image is directly related to the spatial frequency of the object photographed. Widely spaced lines usually result in images with better contrast, or modulation; whereas detail with finely spaced lines results in poor contrast or modulation.
Monitor Site : a point on the ground where a GPS receiver is set up to collect data simultaneously with a GPS receiver in an aircraft.
Optical transfer function: a method of consistently evaluating the image quality produced by an optical system. The OTF value is obtained by measuring the line spread function and then performing a simple Fourier transform. Since the Fourier transform decomposes an image into its sine and cosine frequency components, the OTF describes how the amplitude and phase of an image vary for each spatial frequency received by the imaging system. An OTF of 1 for a particular wavelength means that the spatial frequency is not affected at all. If the OTF is 0, it completely disappears. The OTF consists of the modulation transfer function which describes the effect of the optical system on the set of amplitudes and the phase-transfer function which describes the effect of the optical system on the set of phases. As the geometric information of a scene, such as the resolution, is contained in the amplitude, usually only the modulation transfer function is used.
Radial distortion: causes image points to be displaced in a linear or ray-like direction away from the centre of the image.
Spatial frequency: refers to the different spacing of target bars whose intensity transition from dark to light follows a sine function. As the spatial frequency increases the contrast/sharpness decreases.
Tangential distortion: causes image points to be displaced in a direction normal to radial lines from the centre of the field

APPENDIX 1a

LENS DISTORTION REFERENCE CURVE

The lens distortion reference curves given here have been derived from data provided by the camera manufacturers. They are defined as seven term polynomials and must be used as given.

Î$r = a_1 r + a_3 r^3 + a_5 r^5 + a_7 r^7 + a_9 r^9 + a_{11} r^{11} + a_{13} r^{13}$

where a = coefficient of radial distortion   r = radial distance

Dropping of any polynomial term or of any of the five decimal digits in the multiplicator m_i will invalidate the polynomial. Also, the polynomials should not be used for radial distances r_{max} larger than those given in the following tables. The following figures show the lens distortion curves for all lenses included in the table.

	m_1	m_3	m_5	m_7	m_9	m_{11}	m_{13}	r_{max}
	e_1	e_3	e_5	e_7	e_9	e_{11}	e_{13}	mm
a) Aviogon &	+.35560	-.10141	+.13046	-.12328	+.72154	-.20981	+.23155	148
b) UAg	-00	-03	-07	-11	-16	-20	-25	
c) UAg I	-.18651	+.85656	-.12796	+.97035	-.42728	+.10609	-.11419	148
	-00	-04	-07	-12	-16	-20	-25	
d) UAg II	-.11953	+.88458	-.18839	+.18074	-.87618	+.20144-	.15756	148
	-00	-04	-07	-11	-16	-20	-25	
e) Pleogon	-.14966	+.68872	+.23384	-.82619	-.64853	+.43339	-.69340	153
	-00	-06	-08	-13	-17	-21	-26	
f) Pl A	-.34864	+.13858	-.16051	+.45203	+.21534	-.12427	+.15390	153
	-00	-03	-07	-12	-16	-20	-25	
g) Pl A2	-.11735	+.14841	+.19381	-.25112	+.20896	.48968	-.12900	153
	-00	-04	-08	-12	-17	-21	-25	
h) Pl A2 f/4	+.10003	+.66199	-.19785	+.13384	+.17660	-.10704	+.18059	150
	-01	-05	-08	-13	-16	-20	-25	
i) Lamegon PI/B	-.81564	+.17102	-.13794	+.75864	-.14333	-.51462	+.13987	153
	-01	-04	-08	-13	-17	-22	-26	
j) SAg II	-.15211	-.49155	+.16338	-.11229	+.26084	-.69010	+.23771	148
	-00	-04	-07	-11	-16	-21	-25	
k) SP1 A2	-.42553	+.38240	-.57715	+.18081	+.16878	-.12907	+.24570	150
	-01	-04	-08	-12	-16	-20	-25	
l) Aviotar II	-.13954	+.51530	-.37900	+.94998	+.31924	+.10513	-.50286	148
	-00	-04	-08	-14	-17	-21	-26	
m) Topar A1	+.42387	-.16318	+.56283	+.65450	-.26430	-.39935	+.16608	150
	-01	-04	-09	-13	-17	-22	-26	

Appendix 2a

Example of Aerial Survey Camera Calibration
from the
National Research Centre
Institute for National Measurement Standards

Date: January 01 2000

Report No. OP-1000
Page: 1

CALIBRATION OF AERIAL SURVEY CAMERA
TO THE
SPECIFICATION FOR AERIAL SURVEY PHOTOGRAPHY
for
Aerial Survey Co.
1000 Flight Road
Ottawa, ON
K1A OR6

Author Ian Powell

Approved ________________

for Director

Manufacturer: Wild Lens No.: UAg 10000

Camera Type: RC10 Maximum Aperture: F/5.6

Lens Type: Universal Aviogon Calibration Aperture: F/5.6

Nominal Focal Length: 153 mm Date of Calibration: January 1 2000

Optical Unit No.: UAg 10000 Calibrated Focal Length: 151.413 mm
Photographic Emulsion:Panchromatic

FILTER (Section 62):

Number: 10000 Type: 525nm AV 2.0x
Maximum deviation: 1 Second
Maximum Change of Deviation: 1 Second
Maximum Departure from Parallelism: 1 Second

IMAGE ILLUMINATION (Section 51 & 52):
Minimum 54 % to 140 mm off axis.
CAMERA SHUTTER (Section 43):
Operation: Satisfactory

Speeds

Mark	200	400	600	800	1000
Total Time - Seconds	1/180	1/370	1/520	1/680	1/850
Effective Time - Seconds	1/230	1/480	1/680	1/910	1/1160

Date January 01 2000
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2____

FILM LOCATION SURFACE (Section 54):
Defined by: Fiducial Frame Deviation from Flatness: .005 mm.
FOCUS (Section 48):
Focus Setting: Satisfactory

FOCAL LENGTH (Section 36):

Calibrated focal length: 151.413 mm.
Equivalent focal length: 151.46 mm.

RADIAL MEASURED DISTORTION (Section 46):
Unit-0.001 mm

Angle	Distortion at Semi-Diagonals				Average	Reference
Degrees	1	2	3	4	Distortion	Distortion
5.63	3	5	6	5	5	5
11.25	10	8	5	8	8	8
16.88	11	10	8	7	9	8
22.50	11	5	6	5	6	6
28.13	5	1	1	1	2	2
33.75	0	-6	-4	-4	-4	-7
39.38	-4	-13	-12	-12	-10	-7
42.19	0	-5	-7	-10	-6	-3

Maximum departure of average from reference .003 mm to 42.2 Deg.

ASYMMETRY ABOUT PRINCIPAL POINT OF AUTOCOLLIMATION (Section 46):

Maximum asymmetry .006 mm to 42.2 Deg.

ASYMMETRY ABOUT PRINCIPAL POINT OF BEST SYMMETRY (Section 46)

Maximum asymmetry .003 mm to 42.2 Deg.

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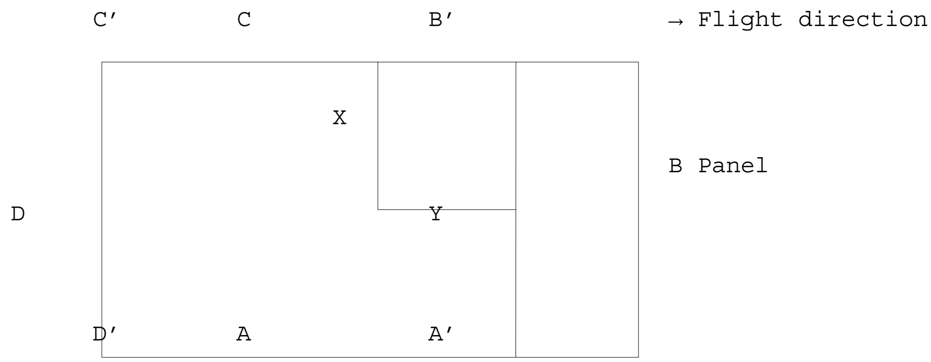
Page: 3

TANGENTIAL MEASURED DISTORTION (Section 46):
Maximum tangential distortion .005 mm to 42.2 Deg.
FIDUCIAL MARKS (Sections 40,41 & 42):
Semi-diagonal 4 Semi-diagonal 3



Semi-diagonal 1 Semi-diagonal 2

Angle between A′C′- B′D′ is 90 deg ± 2 seconds. The fiducial centre is within .024 mm of the point of autocollimation. Distance between the fiducial marks and also between the marks and the principal point of autocollimation, P, are as follows:

A′ - B′ 211.994 mm	A′ - P 149.886 mm
B′ - C′ 212.015 mm	B′ - P 149.892 mm
C′ - D′ 212.008 mm	C′ - P 149.920 mm
D′ - A′ 211.991 mm	D′ - P 149.933 mm

The position of the principal point of autocollimation and of the principal point of best symmetry are given in a rectangular coordinate system as shown, with the fiducial centre as origin.

Principal point of autocollimation (X = -0.015, Y = 0.020) mm.
Principal point of best symmetry (X = -0.009, Y = 0.022) mm.

RESOLUTION MEASURED AT F/5.6:

Area Weighted Average Spatial Frequency = 37 line pairs/mm

Date January 01 2000 Report No. OP-1000

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Note:
The following is a supplementary section which uses the SMAC technique employed by USGS in the United States. Also included is the USGS's format for representing the fiducial marks.

Calibrated focal length: 151.412 mm

Lens Distortion

Field angle (degs):	5.6	11.3	16.9	22.5	28.1	33.7	39.4	42.2
Symmetrical radial (um)	1	2	3	2	1	-2	-8	-11
Decentering (um)	0	0	0	0	0	0	0	1

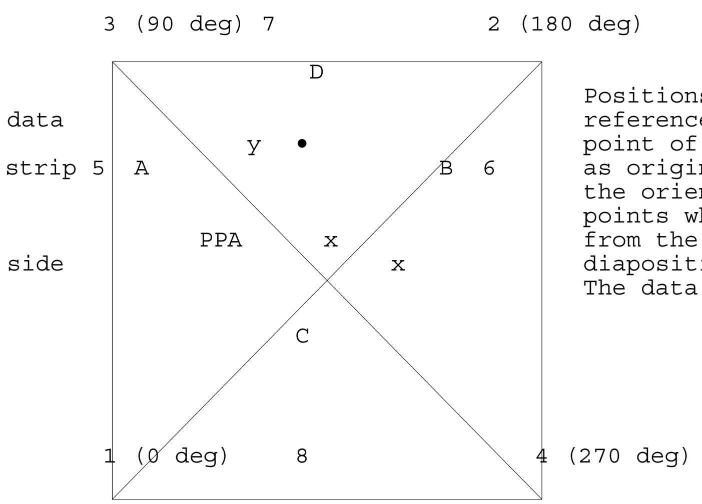
Symmetric radial distortion parameters	Decentering distortion parameters	Calibrated principal point
k0 = 0.9500E-04	pl = 0.8783E-08	xp = 0.000MM
kl = -0.1209E-07	p2 = 0.5076E-07	yp = 0.000MM
k2 = -0.1505E-12	p3 = 0.5345E-05	
k3 = 0.155OE-16		

Angular errors (secs) associated with coordinate systems

lst exposure	x = -1.32	y = 2.38	z = -1.45
2nd exposure	x = 1.72	y = -4.01	z = -2.32

The values and parameters for the calibrated focal length (CFL) symmetrical radial distortion (kl,k2,k3) decentering distortion (pl,p2,p3)and calibrated principal point (point of symmetry, xp,yp) were determined through a least squares simultaneous multiframe analytical calibration (SMAC) adjustment. The x and y coordinate measurements utilized in the adjustment of the above parameters have a standard deviation of +/- 3um.

Principal Points of Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation (PPA) as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back or a contact diapositive with the emulsion up. The data strip is on the left.

	x coord (mm)	y coord (mm)
Indicated principal point, corner fiducials	0.019	-0.015
Principal point of autocollimation (PPA)	0.000	0.000
Calibrated principal point (pt. of sym. xp,yp	0.000	0.000

Fiducial Marks

1	-105.967	-106.004
2	106.025	105.994
3	-105.990	105.989
4	106.024	-106.014

Distances between Fiducial Marks
Corner fiducials (diagonals)
1-2: 299.807mm 3-4: 299.825mm

Lines joining these markers intersect at an angle of 90deg
0 min 2 sec

Corner fiducials (perimeter)
1-3: 211.993 mm 2-3: 212.015 mm
1-4: 211.99l mm 2-4: 212.008 mm

The method of measuring these distances is considered accurate within 0.003mm

Appendix III - References & Literature Cited

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Appendix IV - Species List

alder (Al) .... *Alnus spp*

balsam fir (bF)..*Abies balsamea*
balsam poplar (bP) ....*Populus balsamifera*
bearberry (Be)..*Artctostaphylos uva-ursi*
beaked hazel (Bh) ....*Corylus cornuta*
black spruce (bS)..*Picea mariana*
blueberry (Bb) ....*Vaccinium myrtilloides*
bog birch (Bi) ....*Betula glandulosa*
bog laurel (Bl) ....*Kalmia polifolia*
buffaloberry (Bu) ....*Shepherdia canadensis*
bur oak (bO)..*Quercus macrocarpa*

choke cherry (Pc)... *Prunus virginiana*
currant (Cu)..*Ribes spp.*

gooseberry (Cu)..*Ribes spp*
green alder (Al) ....*Alnus viridis*
green ash (gA) ....*Fraxinus pennsylvanica*
grasses (Gr) ....*Gramminoid spp.*

high-bush cranberry (Cr)... *Viburnum opulus*

jack pine (jP) ....*Pinus banksiana*

Labrador tea (La) ....*Ledum groenlandicum*
leatherleaf (Le)...*Chamaedaphne calyculata*
lodgepole pine (lP)... *Pinus contorta*
lowbush cranberry (Lc) ....*Viburnum edule*

Manitoba maple (mM)..*Acer negundo*
mountain maple (Ma).. *Acer spicatum*

pin cherry (Pc) ....*Prunus pensylvanica*
plains cottonwood (pC) ....*Populus deltoides*
prickley rose (Ro)...*Rosa acicularis*

red-osier dogwood (Dw) ....*Cornus stolonifera*
red pine (rP)..*Pinus resinosa*
river alder (Al) ....*Alnus incana*
rush (Gr) ....*Juncus spp.*

Saskatoon (Sa) ....*Amelanchier alnifolia*
Scots pine (sP) .... *Pinus sylvestris*
sedge (Gr)..*Carex spp.*
shrubby cinquefoil (Ci) ....*Potentilla fruticosa*

Siberian larch (sL).. *Larix sibirica*
sphagnum moss (Mo) .... *Sphagnum spp.*

trembling aspen (tA) .... *Populus tremuloides*
tamarack (tL).. *Larix laricina*

western snowberry (Sn) .... *Symphoricarpos occidentalis*
white birch (wB) .... *Betula papyrifera*
white spruce (wS) ....*Picea glauca*
white elm (wE) ....*Ulnus Americana*
wild red raspberry (Ra) .... *Rubus idaeus*
willow (Wi).. *Salix spp.*