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BASIS FOR CONSISTENT REPRESENTATION OF LAND AREAS

AUTHORS AND REVIEW EDITORS

Co-ordinating Lead Authors

Ronnie Milne (UK) and Bubu Pateh Jallow (The Gambia)

Lead Authors

Dominique Arrouays (France), Peter Beets (New Zealand), Paul Drichi (Uganda), Ismail Bin Harun (Malaysia), James Hrubovcak (USA), Ted Huffman (Canada), William Irving (USA), Michael Koehl (Germany), Erda Lin (China), Lennart Olsson (Sweden), Jim Penman (UK), Ryosuke Shibasaki (Japan), Brian Turner (Australia), Julio C.Vargas (Ecuador) and Ernesto F. Viglizzo (Argentina).

Contributing Author

Ralph Alig (USA)

Review Editors

Mike Apps (Canada) and Jose Domingo Miguez (Brazil)

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2.1 INTRODUCTION

Information about land area is needed to estimate carbon stocks and emissions and removals of greenhouse gases associated with Land Use, Land-Use Change and Forestry (LULUCF) activities. This chapter seeks to provide guidance on the selection of suitable methods for identifying and representing land areas as consistently as possible in inventory calculations.

In practice, countries use methods including annual census, periodic surveys and remote sensing to obtain area data. Starting from this position, Chapter 2 provides *good practice guidance* on three approaches for representing land area. The approaches are intended to provide the area data specified in Chapters 3 and 4 for estimating and reporting greenhouse gas inventories for different categories of land. The approaches are also intended to make the best use of available data and models, and to reduce, as far as practicable, possible overlaps and omissions in reporting land areas. The approaches described here should minimize the chance that some areas of land appear under more than one activity whilst others are overlooked. The approaches and guidance presented here allow informed decisions on these matters to be made by those preparing greenhouse gas inventories but are not intended to be definitive or exhaustive. *Good practice* approaches for representing areas should have the following general characteristics:

- Firstly, the approaches should be *adequate,* i.e., capable of representing carbon stock changes and greenhouse gas emissions and removals and the relations between these and land use and land-use changes.
- Secondly, they should be *consistent,* i.e., capable of representing management and land-use change consistently over time, without being unduly affected either by artificial discontinuities in time series data or by effects due to interference of sampling data with rotational or cyclical patterns of land use (e.g., the harvest-regrowth cycle in forestry, or managed cycles of tillage intensity in cropland).
- Thirdly, the approaches should be *complete*, which means that all land area within a country should be included, with increases in some areas balanced by decreases in others where this occurs in reality, and should recognise subsets of land used for estimation and reporting according to definitions agreed in the Marrakesh Accords for Parties to the Kyoto Protocol.
- Finally, the approaches should be *transparent*, i.e., data sources, definitions, methodologies and assumptions should be clearly described.

2.2 LAND-USE CATEGORIES

Six broad categories[1] of land are described in this section. These may be considered as top-level categories for representing land areas within a country. The categories are consistent with the *IPCC Guidelines* and the requirements of Articles 3.3 and 3.4 of the Kyoto Protocol, and may be further subdivided as described in Chapters 3 and 4 of this report. The categories are broad enough to classify all land areas in most countries and to accommodate differences in national classification systems. These national classification systems should be used consistently over time. The categories are intended for use in conjunction with the approaches described in subsequent sections of this chapter to facilitate consistent estimation of land use over time. This does not imply that carbon stock changes or greenhouse gas emissions and removals need be estimated or reported for areas where this is not required by the *IPCC Guidelines* or for some countries, the Marrakesh Accords[2].

It is recognized that the names of these land categories are a mixture of land cover (e.g., Forest land, Grassland, Wetlands) and land use (e.g., Cropland, Settlements) classes. For convenience, they are here referred to as land-use categories. These particular categories have been selected because they are:

- Reasonably consistent with the *IPCC Guidelines;*
- Robust as a basis for carbon estimation;
- Reasonably mappable by remote sensing methods; and

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[1] The basic categories are generally consistent with on-going work on harmonizing forest-related definitions by Food and Agriculture Organisation (FAO), IPCC, International Union of Forestry Research Organizations (IUFRO) and Centre for International Forestry Research (CIFOR) (FAO 2002), with definitions for forestry and other land use types by the United States Geological Survey (USGS (2001)), FAO (1986, 1995) described by IPCC (2000), and with the definitions adopted for land use under the Kyoto Protocol and Marrakesh Accords (FCCC/CP/2001/13/Add.1, p58).

2 Carbon stock changes and greenhouse gas emissions on unmanaged land are not reported under the *IPCC Guidelines*, although reporting is required when unmanaged land is subject to land use conversion.

- Complete in that all land areas should be represented in one or another category.

Care will be needed in inferring land use from these categories. For example, in some countries significant areas of the forest land category may be grazed, and firewood may be collected from scattered trees in the grassland category lands. These areas with different use may be significant enough for countries to consider them separately in which case it is *good practice* to make these additional classes subcategories of the suggested high-level categories and to ensure that all land is accounted for.

Countries will use their own definitions of these categories, which may, of course, refer to internationally accepted definitions, such as those by FAO, Ramsar, etc. For that reason no definitions are given here beyond broad descriptions. Managed land may be distinguished from that unmanaged by fulfilling not only the production but also ecological and social functions. The detailed definitions and the national approach to distinguishing between unmanaged and managed land should be described in a transparent manner.

The top-level land categories for greenhouse gas (GHG) inventory reporting are:

(i) Forest land

This category includes all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory, sub-divided into managed and unmanaged, and also by ecosystem type as specified in the *IPCC Guidelines*[3]. It also includes systems with vegetation that currently fall below, but are expected to exceed, the threshold of the forest land category.

(ii) Cropland

This category includes arable and tillage land, and agro-forestry systems where vegetation falls below the thresholds used for the forest land category, consistent with the selection of national definitions.

(iii) Grassland

This category includes rangelands and pasture land that is not considered as cropland. It also includes systems with vegetation that fall below the threshold used in the forest land category and are not expected to exceed, without human intervention, the threshold used in the forest land category. The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, subdivided into managed and unmanaged consistent with national definitions.

(iv) Wetlands

This category includes land that is covered or saturated by water for all or part of the year (e.g., peatland) and that does not fall into the forest land, cropland, grassland or settlements categories. The category can be subdivided into managed and unmanaged according to national definitions. It includes reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions.

(v) Settlements

This category includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. This should be consistent with the selection of national definitions.

(vi) Other land [4]

This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. It allows the total of identified land areas to match the national area, where data are available.

When applying these categories, inventory agencies should classify land under only one category to prevent double counting. If a country's land classification system does not match categories (i) to (vi) as described above, it is *good practice* to combine or disaggregate the existing land classes of this system of land-use classification in order to use the categories presented here, and to report on the procedure adopted. It is also *good practice* to specify national definitions for all categories used in the inventory and report any threshold or parameter values used in the definitions. Where national land classification systems are being changed or developed for the first time, it is *good practice* to ensure their compatibility with land-use classes (i) to (vi).

The broad categories listed above provide the framework for the further sub-division by activity, management regime, climatic zone and ecosystem type as necessary to meet the needs of the methods for assessing carbon stock changes and greenhouse gas emissions and removals described in Chapter 3 (LUCF Sector Good Practice

[3] Forest management has particular meaning under the Marrakesh Accords, which may require subdivision of the managed forest as described in Chapter 4.

[4] Carbon pools would not need to be assessed for this category, but it is included for checking overall consistency of land area.

Guidance) and Chapter 4 (Supplementary Methods and Good Practice Guidance arising from the Kyoto Protocol) and allows comparison with *IPCC Guidelines* categories 5A to 5E. Section 3.1.2 and Table 3.1.1 (Mapping between the sections of Chapter 5 of the *IPCC Guidelines* and the sections of Chapter 3 of this report) describe how to relate the structure of methods described in this report to those of the *IPCC Guidelines*.

2.3 REPRESENTING LAND AREAS

2.3.1 Introduction

This section describes three approaches for representing land areas using the broad categories defined in the previous section. They are presented below in order of increasing information content. Approach 1 identifies the total area for each individual land-use category, but does not provide detailed information on changes of area between categories and is not spatially explicit other than at the national or regional level. Approach 2 introduces tracking of land-use changes between categories. Approach 3 extends Approach 2 by allowing land-use changes to be tracked on a spatial basis.

The approaches are not presented as hierarchical tiers; they are not mutually exclusive, and the mix of approaches selected by an inventory agency should reflect calculation needs and national circumstances. One approach may be applied uniformly to all areas and land-use categories within a country, or different approaches may be applied to different regions or categories or in different time intervals. In all cases, it is *good practice* to characterise and account for all relevant land areas in a country. Using *good practice* in the application of any of the approaches will increase accuracy and precision in area estimation for inventory purposes. Decision trees to assist in selecting an appropriate approach or mix of approaches are given in Section 2.3.3 (Using the Approaches).

All approaches require collection of data for estimating the historical trends in land use, which are needed for the inventory methods described in the *IPCC Guidelines* and Chapters 3 and 4 of this report. The amount of historical data required will be based on the amount of time needed for stored carbon to reach equilibrium (often 20 years in the IPCC default methods, but longer for temperate and boreal systems). Where independent data are available, it is *good practice* to verify estimates based on interpolation or extrapolation using the methods set out in Chapter 5, Section 5.7 of this report. All approaches are capable of producing input to uncertainty calculations discussed in Chapter 5 (Cross-cutting Issues).

A hypothetical example of each approach is provided below along with the description, and real-world examples are provided in Annex 2A.1.

2.3.2 Three Approaches

2.3.2.1 APPROACH 1: BASIC LAND-USE DATA

Approach 1 is probably the most common approach used at present for preparing estimates of emissions and removals under *IPCC Guidelines* categories 5A-5E. It uses area datasets likely to have been prepared for other purposes such as forestry or agricultural statistics. Frequently, several datasets will be combined to cover all land classifications and regions of a country. The absence of a unified data system can lead to double counting or omission, since the agencies involved may use different definitions of specific land use for assembling their databases. This report suggests ways to deal with this. Coverage must obviously be complete enough to include all land areas affected by the activities set out in Chapter 5 of the *IPCC Guidelines,* but might not extend to categories such as unmanaged ecosystems, wetlands or settlements.

When implementing Approach 1, it is *good practice* to:

- Harmonise definitions between the existing independent databases and also with the broad land-use categories of Section 2.2 (Land-Use Categories) to minimise gaps and overlaps. For example, if woodland on farms were included both in forestry and agricultural datasets, overlaps might occur. In order to harmonise data, the woodland should be counted only once for greenhouse gas inventory purposes, taking into account the forest definitions adopted nationally. Information on possible overlaps for the purposes of harmonisation should be available from agencies responsible for surveys. Harmonisation of definitions does not mean that agencies should abandon definitions that are of use to them. It is consistent with *good practice* to establish the relationship between definitions in use with the aim of eliminating double counting and omissions. This should be done throughout the dataset to maintain time series consistency.

- Ensure that the land-use categories used can identify all relevant activities. For example, if a country needs to track a land-use activity such as forest management, then the classification system should be able to distinguish managed from unmanaged forest areas.
- Ensure that data acquisition methods are reliable, well documented methodologically, timely, at an appropriate scale, and from reputable sources. Reliability can be achieved by using surveys that can be related to the harmonised definitions. Ground surveys can be cross-checked where independent data sources are available and will be needed for checking the accuracy of remote sensing data, where used (See Chapter 5.7-Verification). International datasets are also available for cross-checking (see Annex 2A.2).
- Ensure the consistent application of category definitions between time periods. For example, countries should check whether the definition of forest has changed over time in terms of canopy cover and other thresholds. If changes are identified, it is *good practice* to correct the data using the back-casting methods described in Chapter 5 of this report to ensure consistency throughout the time series, and report on actions taken.
- Construct uncertainty estimates for those land category areas and changes in area that will be used in the estimation of carbon stock changes, emissions and removals (see Chapter 5 Section 5.3.4.1).
- Assess whether the sum of the areas in the land classification databases is consistent with the total territorial area, given the level of data uncertainty. If coverage is complete, then the net sum of all the changes between two time periods should be zero to within the uncertainties involved. In cases where coverage is incomplete, the difference between the area covered and the territorial area should, in general, be stable or vary slowly with time, again to within the uncertainties expected in the data. If the balancing term varies rapidly, or (in the case of complete coverage) sums are not equal, it is *good practice* to investigate, explain, and make any corrections necessary. These checks on the total area should take into account the expected uncertainties in the annual or periodic surveys or censuses involved. Information on expected uncertainties should be obtained from the agencies responsible for the surveys. Usually there will be remaining differences between the sum of areas accounted for by the available data and the national area. It is *good practice* to keep track of these differences and to provide an explanation for the likely causes. Carbon stock changes and emissions and removals of greenhouse gases implied by variation through time of these differences may be due to land-use change and may therefore need to be accounted for in the GHG inventory as required by the methods set out in Chapters 3 and 4.

Tables 2.3.1 and 2.3.2 show summary land area data for a hypothetical country (total area 140 Mha) using locally relevant land classifications. Table 2.3.1 is prepared at the level of categories (i) to (vi) and Table 2.3.2 depicts the same information with example subdivisions to estimate the effect of various activities using the methods in Chapter 3. Table 2.3.2 also indicates where in Chapter 3 the inventory methods can be found. It is *good practice* to prepare tables similar to Table 2.3.1 or 2.3.2 as part of the quality assurance and quality control (QA/QC) procedures as set out in Chapter 5.

TABLE 2.3.1
EXAMPLE OF APPROACH 1:
AVAILABLE LAND -USE DATA WITH COMPLETE TERRITORIAL COVERAGE

Time 1			**Time 2**			**Land-Use Change between Time 1 and Time 2**		
F	=	18	F	=	19	Forest	=	+1
G	=	84	G	=	82	Grassland	=	-2
C	=	31	C	=	29	Cropland	=	-2
W	=	0	W	=	0	Wetlands	=	0
S	=	5	S	=	8	Settlements	=	+3
O	=	2	O	=	2	Other land	=	0
Sum	=	*140*	*Sum*	=	*140*	*Sum*	=	*0*

Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land. Numbers represent area units (Mha in this example).

TABLE 2.3.2 ILLUSTRATIVE EXAMPLE OF SUB-DIVISION OF DATA FOR APPROACH 1					
Land-Use Category Land-Use Subcategory	**Initial land area Mha**	**Final land area Mha**	**Net Change in area Mha**	***Good practice Guidance* Methods Section Number in Chapter 3 of this Report**	**Comment on subdivision by activity (illustrative only)**
Forest land total	**18**	**19**	**1**		
Forest land (Unmanaged)	5	5	0		Not included in the inventory estimates
Forest land zone A (with deforestation)	7	4	-3	3.2.1/3.4.2/3.6	
Forest land zone B	6	6	0	3.2.1	No LUC. Could require subdivision for different management regimes etc.
Afforestation	0	4	4	3.2.2	Could require subdivision e.g. by ecosystem type
Grassland total	**84**	**82**	**-2**		
Unimproved grassland	65	63	-2	3.4.1/3.2.2/3.6	Fall in area indicates LUC. Could require subdivision for different management regimes etc.
Improved grassland	19	19	0	3.4.1	No LUC. Could require subdivision for different management regimes etc.
Cropland total	**31**	**29**	**-2**		
All Cropland	31	29	-2	3.3.1/3.2.2/3.6	Fall in area indicates LUC. Could require subdivision for different management regimes etc.
Wetlands total	**0**	**0**	**0**		
Settlements total	**5**	**8**	**3**		
Existing Settlements	5	5	0	3.6	
New Settlements	0	3	3	3.6	
Other land total	**2**	**2**	**0**	3.7.1	Unmanaged - not in inventory estimates
Balancing term	0	0	0		
TOTAL	**140**	**140**	**0**		
Note: "Initial" is the category at a time previous to the date for which the assessment is made and "Final" is the category at the date of assessment. Activities for which location data are not available should be identified by further sub-division of an appropriate Land Category.					

Determination of the area of land-use change in each category is based on the difference in area at two points in time, either with partial or full land area coverage. No specification of inter-category changes is possible under Approach 1 unless supplementary data are available (which would of course introduce a mix with Approach 2). The land-use distribution data may come originally from sample survey data, maps or censuses (such as landowner surveys), but will probably not be spatially explicit[5] in the form used. The sum of all land-use categories may not equal the total area of the country or region under consideration, and the net result of land-use changes may not equal zero. The final result of this approach is a table of land use at given points in time.

2.3.2.2 APPROACH 2: SURVEY OF LAND USE AND LAND-USE CHANGE

The essential feature of Approach 2 is that it provides a national or regional-scale assessment of not only the losses or gains in the area of specific land categories but what these changes represent (i.e., changes from and to a category). Thus, Approach 2 includes more information on changes between categories. Tracking land-use changes in this explicit manner will normally require estimation of initial and final land-use categories, as well

[5] When considering the possibility of adopting Approach 2 or 3, it is useful to investigate with the data collection agencies whether the original data sources contain spatially explicit data. For example, forest inventories are usually derived from spatially explicit data sources.

as of total area of unchanged land by category. The final result of this approach can be presented as a non-spatially explicit land-use change matrix. The matrix form is a compact format for representing the areas that have come under different transitions between all possible land-use categories. Existing land-use databases may have sufficient detail for this approach, or it may be necessary to obtain data through sampling. The input data may or may not have originally been spatially explicit (i.e., mapped or otherwise geographically referenced). Sample data will be extrapolated using the ratio to the total relevant area or the total relevant population. Data will require periodic re-survey of a statistically and spatially valid sample of sites chosen according to the principles set out in Section 5.3 (Sampling) of Chapter 5.

Although Approach 2 is more data intensive than Approach 1, it can account for all land-use transitions. This means that emission and removal factors or parameters for rate of change of carbon can be chosen to reflect differences in the rate of changes in carbon in the opposing directions of transitions between any two categories, and differences in initial carbon stocks associated with different land uses can be taken into account. For example, the rate of soil organic carbon loss will commonly be much higher through ploughing than the rate of re-accumulation if cultivation is subsequently abandoned, and initial carbon stocks may be lower for transitions from cropland than from pasture.

Good practice points described for Approach 1 also apply to Approach 2, although at a greater level of detail, since the pattern of land-use change is available, not just the net change into or out of each land category or subcategory.

Approach 2 is illustrated in Table 2.3.3 using the data from the Approach 1 example (Table 2.3.2) by adding information on all the transitions taking place. Such data can be written in the more compact form of a matrix and this is presented in Table 2.3.4. To illustrate the added value of Approach 2 and this land-use change matrix format, the data of Table 2.3.4 is given in Table 2.3.5 without the subdivision of the land-use categories and this can be compared with the more limited information from Approach 1 in Table 2.3.1. In Table 2.3.5, the changes into and out of land categories can be tracked, whereas in Table 2.3.1 only the net changes in a broad category are detectable. When using Approach 2, it is *good practice* to prepare a table like Table 2.3.4 or 2.3.5 as part of QA/QC procedures as set out in Chapter 5.

TABLE 2.3.3
ILLUSTRATIVE EXAMPLE OF TABULATING ALL TRANSITIONS FOR APPROACH 2
INCLUDING NATIONALLY DEFINED SUB-CATEGORIES

Initial Land Use	**Final Land Use**	**Land Area Mha**	***Good Practice* Guidance Methods Section No. in Chapter 3 of this Report**
Forest land (Unmanaged)	Forest land (Unmanaged)	5	Excluded from GHG inventory
Forest land (Managed)	Forest land(Managed)	10	3.2.1
	(Forest zone A Table 2.3.2)	*4*	
	(Forest zone B Table 2.3.2)	*6*	
Forest land (Managed)	Grassland (Rough grazing)	2	3.4.2
Forest land (Managed)	Settlements	1	3.6
Grassland (Rough grazing)	Grassland (Rough grazing)	56	3.4.1
Grassland (Rough grazing)	Grassland (Improved)	2	3.4.1
Grassland (Rough grazing)	Forest land (Managed)	1	3.2.2
Grassland (Rough grazing)	Settlements	1	3.6
Grassland (Improved)	Grassland (Improved)	22	3.4.1
Grassland (Improved)	Forest land (Managed)	2	3.2.2
Cropland	Cropland	29	3.3.1
Cropland	Forest land (Managed)	1	3.2.2
Cropland	Settlements	1	3.6
Wetlands	Wetlands	0	
Settlements	Settlements	5	3.6
Other land	Other land	2	Excluded from GHG inventory
TOTAL		**140**	

Note: Data are subdivided version of those in Table 2.3.2. Sub-categories are nationally defined and are illustrative only. “Initial” indicates the category at a time previous to the date for which the assessment is made and “Final” the category at the date of assessment.

TABLE 2.3.4
ILLUSTRATIVE EXAMPLE OF APPROACH 2 DATA IN A LUC MATRIX WITH CATEGORY SUBDIVISIONS

Final \ Initial	Forest land (Unmanaged)	Forest land (Managed)	Grassland (Rough grazing)	Grassland (Improved)	Cropland	Wetlands	Settlements	Other land	Final area
Forest land (Unmanaged)	5								**5**
Forest land (Managed)		10	1	2	1				**14**
Grassland (Rough grazing)		2	56						**58**
Grassland (Improved)			2	22					**24**
Cropland					29				**29**
Wetlands						0			**0**
Settlements		1	1		1		5		**8**
Other land								2	**2**
Initial area	**5**	**13**	**60**	**24**	**31**	**0**	**5**	**2**	**140**
NET change	0	+1	-2	0	-2	0	+3	0	**0**

Note: Column and row totals show net changes in land use as presented in Table 2.3.2 but subdivided into national subcategories as in Table 2.3.3. "Initial" indicates the category at a time previous to the date for which the assessment is made and "Final" the category at the date of assessment. Net changes (bottom row) are the final area minus the initial area for each of the (sub) categories shown at the head of the corresponding column. Blank entry indicates no land-use change for this transition.

TABLE 2.3.5
SIMPLIFIED LAND-USE CHANGE MATRIX FOR EXAMPLE APPROACH 2

Land-Use Change Matrix

Final \ Initial	F	G	C	W	S	O	*Final sum*
F	**15**	3	1				***19***
G	2	**80**					***82***
C			**29**				***29***
W							
S	1	1	1		**5**		***8***
O						**2**	***2***
Initial sum	***18***	***84***	***31***		***5***	***2***	*140*

Note:
F = Forest land, G = Grassland, C = Cropland, W = Wetlands,
S = Settlements, O = Other land
Numbers represent area units (Mha in this example).
There is no Wetlands in this example. Blank entry indicates no land use change.

Further subcategorisations, for example by forest species or combinations of species and soil type, are likely to be required by many countries when they implement this Approach, in order to provide data on the land areas needed for estimating carbon stock changes taking account of the guidance in Chapter 3. Table 2.3.3 illustrates possible subdivisions, and indicates where in Chapter 3 to find methodological guidance on particular land uses or transitions.

2.3.2.3 APPROACH 3: GEOGRAPHICALLY EXPLICIT LAND USE DATA

Approach 3 (summarised in Figure 2.3.1) requires spatially explicit observations of land use and land-use change. The data may be obtained either by sampling of geographically located points, a complete tally (wall-to-wall mapping), or a combination of the two.

Approach 3 is comprehensive and relatively simple conceptually but data intensive to implement. The target area is subdivided into spatial units such as grid cells or polygons appropriate to the scale of land-use variation and the unit size required for sampling or complete enumeration. The spatial units must be used consistently over time or bias will be introduced into the sampling. The spatial units should be sampled using pre-existing map data (usually within a Geographic Information System (GIS)) and/or in the field and the land uses should be observed or inferred and recorded at the time intervals required by Chapter 3 or 4 methods. If wall-to-wall mapping is used, a polygon based approach can be used equivalently to a grid approach, see Figure 2.3.1. Observations may be from remote sensing, site visits, oral interviews, or questionnaires. Sampling units may be points, or areas from 0.1 ha to a square kilometre or more, depending on the sample design. Units can be sampled statistically on a sparser interval than would be used for the complete coverage, chosen at regular or irregular intervals, and can be concentrated in areas where land-use change is expected. Recorded data could be of land use at a point or within a sampling unit on each occasion but could also include land-use change data within a sampling unit between the sampling years.

For effective implementation of Approach 3, the sampling needs to be sufficient to allow spatial interpolation and thus production of a map of land use. Sampling methods and associated uncertainties are discussed in the sampling section of Chapter 5 (Section 5.3). All LULUCF activities in each spatial unit or collection of the units are then tracked over time (periodically but not necessarily annually) and recorded individually, usually within a GIS. Because Approach 3 is similar to Approach 2, summary Table 2.3.4 or 2.3.5 as described under Approach 2 should be prepared for this approach as part of QA/QC procedures as set out in Chapter 5.

Figure 2.3.1 Overview of Approach 3: Direct and repeated assessments of land use from full spatial coverage

Description

Under Approach 3 the country is subdivided into spatial units such as grid cells or small polygons. In this example grid cells are used for subdivision of the area. The grid cells are sampled by remote sensing and ground survey, in order to establish the areas of the land use whose estimated extent is shown by the grey lines below the grid. Remote sensing enables complete coverage of all grid cells (Figure 2.3.1A) in the interpretation of land use. Ground surveys will be carried out in a sample of grid cells and can be used to establish land use directly as well as to help interpret remote sensed data. The sample of grid cells can be distributed regularly (Figure 2.3.1B) or irregularly (Figure 2.3.1C), for example, to give greater coverage where LUC is more likely. Maps can be prepared using the grid cells, which can also be aggregated into polygons (Figure 2.3.1D). The final result of the approach is a spatially explicit land-use change matrix.

Time 1 **Time 2**

Figure 2.3.1A

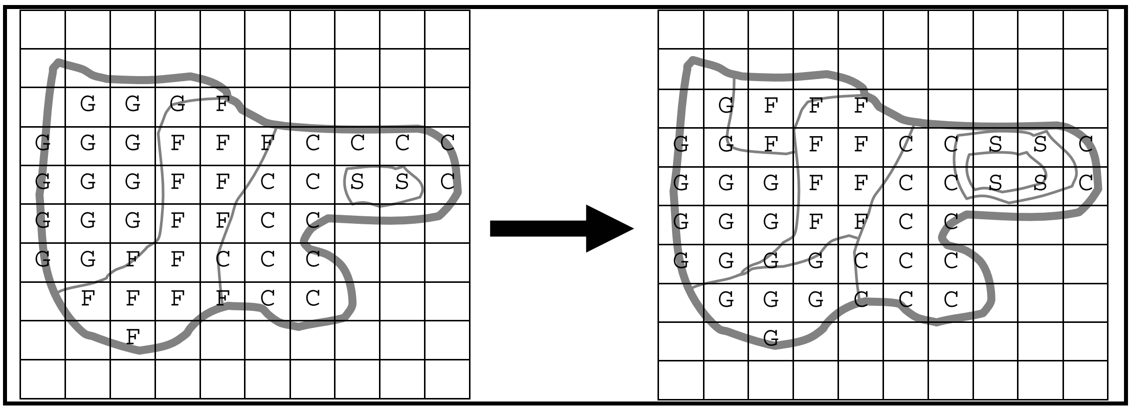


Figure 2.3.1.B

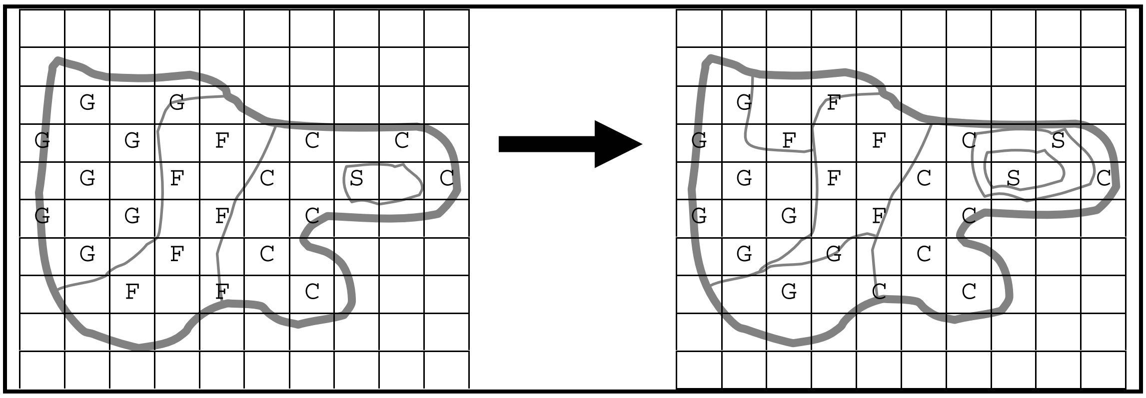


Figure 2.3.1C

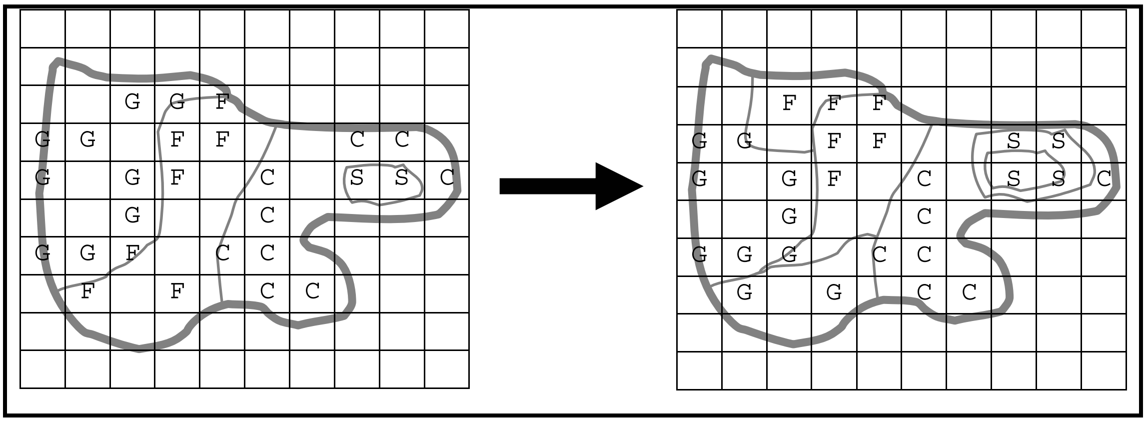
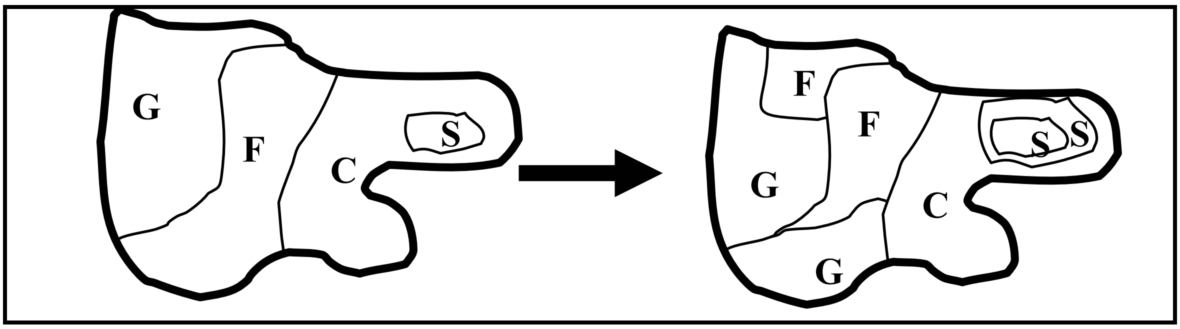


Figure 2.3.1D



Note: F = Forest land, G = Grassland, C = Cropland, W = Wetlands, S = Settlements, O = Other land.

Data, using either a grid or polygons, at a fine scale could directly account for units of land on which afforestation, reforestation or deforestation has occurred under Article 3.3. Gridded data may be available from remote sensing and will normally be combined with ancillary mapped data (such as forest inventories or soil maps) to improve the accuracy of land-use classification. The building of models to relate remote sensing to ground truth data is a highly skilled process, and hence is discussed in more detail in Section 2.4.4.1 (Remote sensing techniques).

When using Approach 3, it *is good practice* to:

- Use a sampling strategy consistent with the approaches and advice provided in Section 2.4.2 and Section 5.3 of Chapter 5. This strategy should ensure that the data are unbiased and can be scaled up where necessary. The number and location of the sampling units may need to change over time in order to remain representative. Advice on time evolution is given in Section 5.3.3 (Sampling design) in Chapter 5.
- Where remote sensing data are used, develop a method for its interpretation into land categories using ground reference data as set out in Section 2.4.4.1 (Remote sensing techniques). Conventional forest inventories or other survey data can be used for this. It is necessary to avoid possible misclassification of land types – e.g., wetlands may be difficult to distinguish from forest land using remote sensing data alone thereby requiring ancillary data such as soil type or topography. Hence map accuracy can be established by means of ground reference data as outlined in the same section. The conventional technique is to establish a matrix[6] showing, for any given classification of land, the probability of misclassification as one of the other candidate classifications.
- Construct confidence intervals for those land category areas and changes in area that will be used in the estimation of carbon stock changes, emissions and removals (see Chapter 5 Section 5.3.4.1).
- Derive summary tables of the national areas under different land-use change (similar to those described for Approach 2 for QA/QC purposes.

2.3.3 Using the Approaches

Figures 2.3.2 and 2.3.3 are decision trees to assist in choosing an appropriate approach or mix of approaches for identifying land-use areas. All three approaches can, if implemented consistently with the requirements in Chapters 3 to 5, be used to produce greenhouse gas emission and removal estimates that are consistent with *good practice*. In general, Approach 3 will allow for the spatial representation required as an input to spatially based carbon models (described in Chapter 3).

The use of one or more approaches in a country will depend on, amongst other factors, spatial variability, the size and accessibility of remote areas, the history of biogeographical data collection, the availability of remote sensing staff and resources (outsourced, if necessary) and the availability of spatially explicit carbon data and/or models. Most countries will have some existing land-use data and the decision tree in Figure 2.3.2 is provided to assist in using this data in ways that meet the guidance in this Chapter. There are three key decisions to be taken: is spatially explicit data required for Kyoto Protocol reporting, do the data cover the whole country and do they provide an adequate time series.

For the few countries with no existing data, the decision tree in Figure 2.3.3 is provided to assist in choosing an appropriate approach or mix of approaches. Broadly speaking, good accessibility to all land area and/or limited remote sensing resources are indicators for greater emphasis on field survey methods to develop land-use databases. Countries with more difficult access to some locations but with access to good remote sensing data, should consider Approach 3 with an emphasis on remote sensing. Approach 2 may be more appropriate in countries where the land area is large but resources to handle the extensive high resolution data required by Approach 3 are not available. Countries with poor accessibility and limited remote sensing resources are unlikely to be able to develop databases suitable for Approach 2 or 3 but should be able to use Approach 1, either from FAO data (database on land use and land cover) or other internationally available databases (e.g., see Annex 2A.2).

Different Approaches may be more effective over different time periods, or may be required for different reporting purposes. Chapter 5 provides methods to carry out matching of the time series between the different periods or uses that are likely to be necessary.

[6] Sometimes called the *confusion matrix*.

Figure 2.3.2 Decision tree for use of existing data in the land area approaches

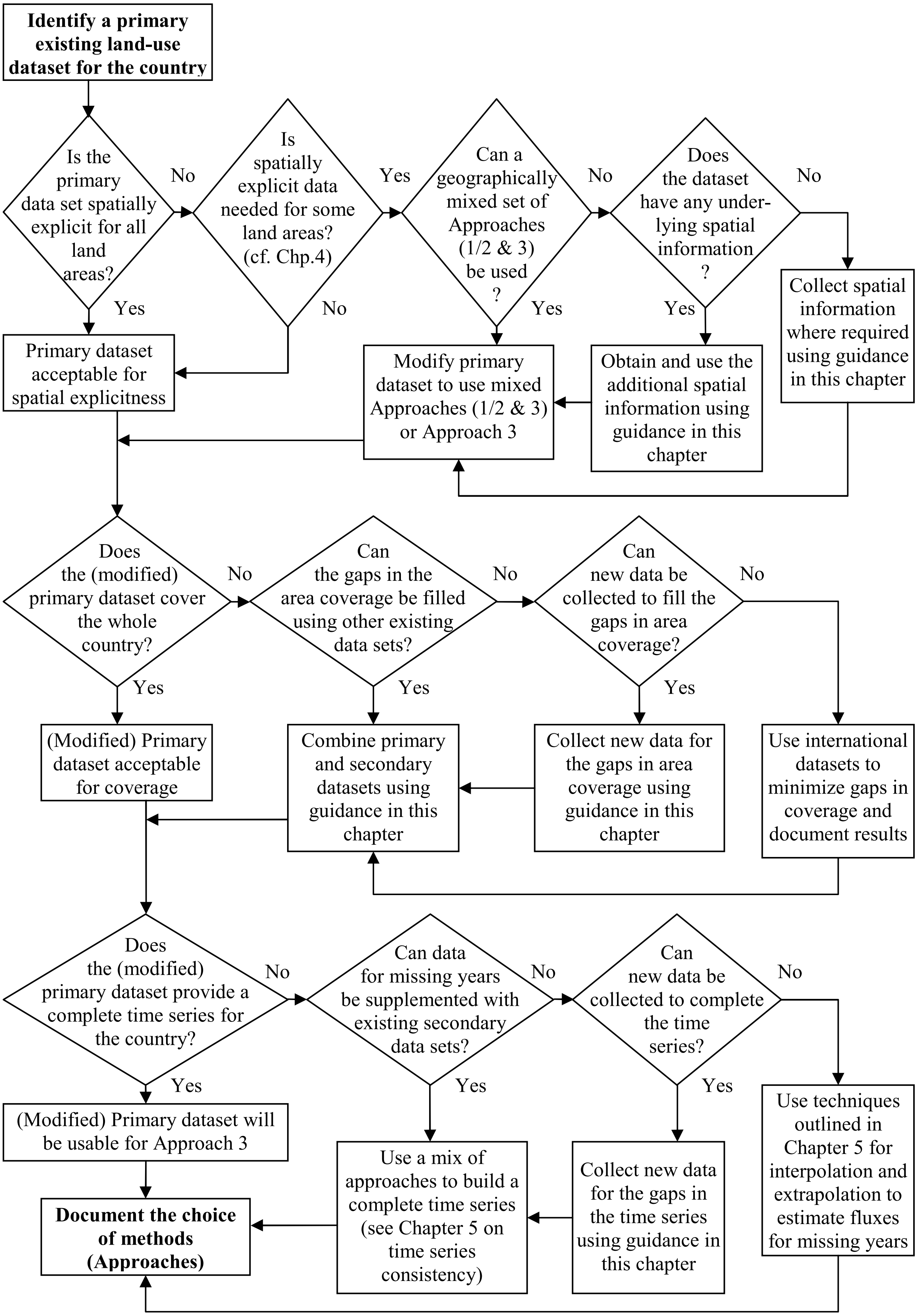
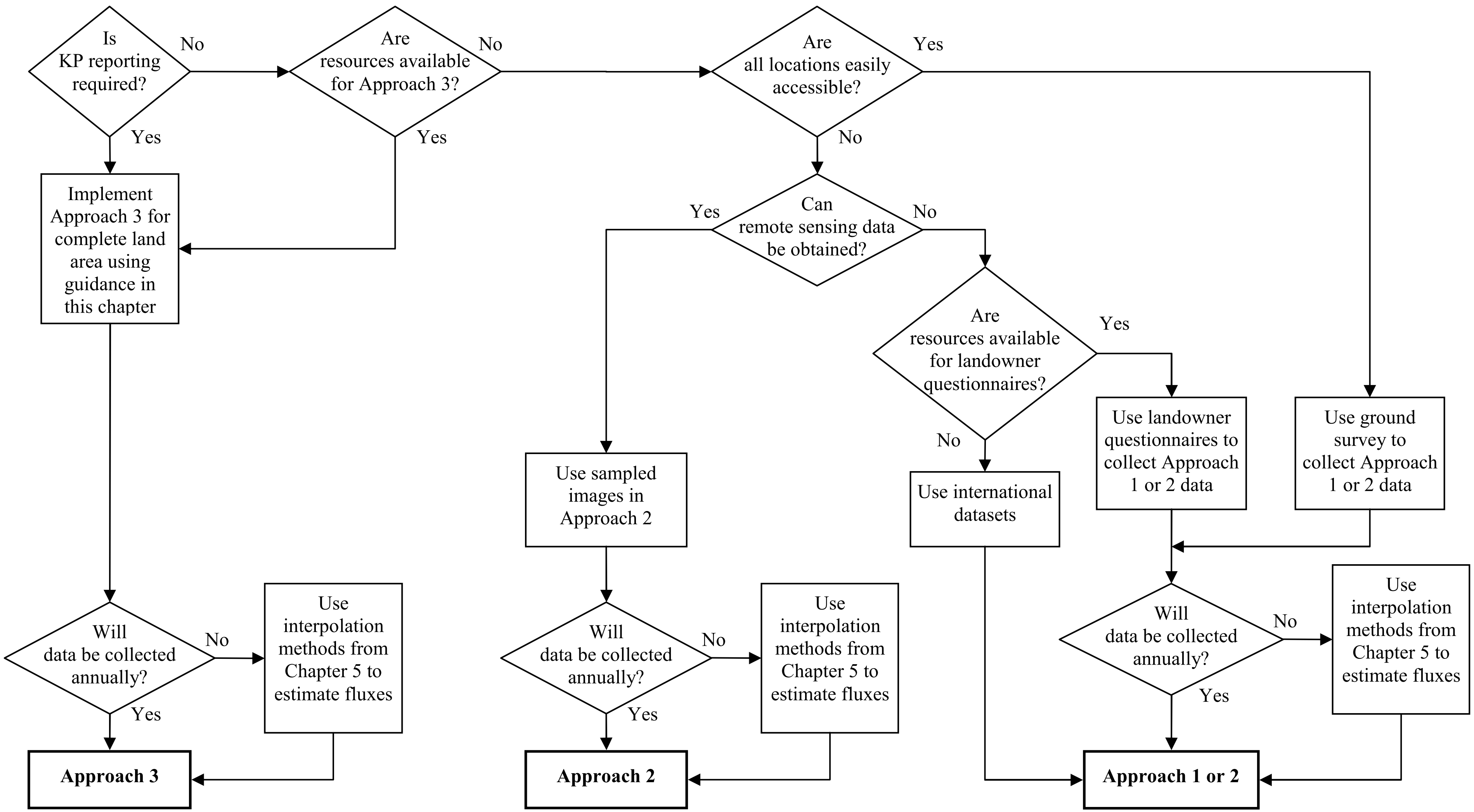


Figure 2.3.3 Decision tree for choosing land area approach for countries with no existing data



2.3.4 Uncertainties Associated with the Approaches

Good practice requires uncertainties to be reduced as far as practicable and Chapter 5.2 (Identifying and quantifying uncertainties) sets out methods to quantify them. These methods require area uncertainty estimates as an input. Although the uncertainty associated with the Approaches 1 to 3 obviously depends on how they are implemented and on the quality of the data available, it is possible to give an indication of what can be achieved in practice. Table 2.3.6 sets out the sources of uncertainty involved, the basis for reducing uncertainties and indicative levels of uncertainty under conditions that might be encountered in practice.

The sources of uncertainty of area will tend to increase from Approach 1 to Approach 3, because successively more data are brought into the assessment. This does not imply that uncertainty increases, however, because of the additional cross-checks that are made possible by the new data, and because of the general reduction in uncertainties due to cancellation of errors familiar in statistics. The main difference between Approach 1, and Approaches 2 and 3 is that percentage uncertainties on changes in land area are likely to be greater in Approach 1. This is because in Approach 1 changes in land use are derived from differences in total areas. Under Approach 1, the uncertainty in the difference will be between 1 and 1.4 times the uncertainty in areas being compared, depending on the degree of correlation between the surveys. Approach 3 produces detailed spatially explicit information; which may be required e.g., for some modelling approaches, or for reporting Kyoto Protocol activities. In these cases additional spatial information would be needed if Approach 1 or 2 is being used for land area identification. Kyoto Protocol requirements are identified in Chapter 4, Section 4.2.2.

TABLE 2.3.6
SUMMARY OF UNCERTAINTIES UNDER APPROACHES 1 TO 3

	Sources of uncertainty	**Ways to reduce uncertainty**	**Indicative uncertainty following checks**
Approach 1	Sources of uncertainty may include some or all of the following, depending on the nature of the source of data: • Error in census returns • Differences in definition between agencies • Sampling design • Interpretation of samples In addition: Cross-checks on area changes between categories cannot be conducted under Approach 1 and this will tend to increase uncertainties.	• Check for consistent relationship with national area • Correct for differences in definitions • Consult statistical agencies on likely uncertainties involved • Compare with international datasets	Order of a few % to order of 10% for total land area in each category. Greater % uncertainty for changes in area derived from successive surveys. Systematic errors may be significant when data prepared for other purposes is used.
Approach 2	As Approach 1 with ability to carry out cross-checks	As above plus consistency checks between inter-category changes within the matrix	Order of a few % to order of 10% for total land area in each category, and greater for changes in area, since these are derived directly
Approach 3	As Approach 2 plus uncertainties linked to interpretation of remote sensing data, where used	As Approach 2 plus formal analysis of uncertainties using principles set out in Chapter 5	As Approach 2, but areas involved can be identified geographically. However, using Approach 3 the amount of uncertainty can be determined more accurately, than for Approach 2.

2.4 DEVELOPMENT OF LAND-USE DATABASES

There are three broad ways to develop the land-use databases needed for greenhouse gas inventories:

- Use of existing databases prepared for other purposes;
- Use of sampling, and
- Use of complete land inventories.

The following subsections provide general *good practice* advice on the use of these types of data for consideration by inventory agencies in consultation with other agencies responsible for provision of statistical data at the national level. Inventory preparers might not be involved in the detailed collection of remote sensing data or ground survey data, but can use the guidance provided here to help plan inventory improvements and communicate with experts in these areas.

2.4.1 Use of Data Prepared for Other Purposes

Two types of available databases may be used to classify land. In many countries, national datasets of the type discussed below will be available. Otherwise, inventory agencies may use international datasets. Both types of databases are described below.

National databases

Approaches 1 and 2 will usually be based on existing data, updated annually or periodically. Typical sources of data include forest inventories, agricultural census and other surveys, censuses for urban and natural land, land registry data and maps. Use of this information is illustrated by the examples in Annex 2A.1: Examples of Approaches in individual countries. *Good practice* in using data of this type is set out in Section 2.3.2.1.

International databases

Several projects have been undertaken to develop international land-use and land-cover datasets at regional to global scales (Annex 2A.2 lists some of these datasets). Almost all of these datasets are stored as raster data[7] generated using different kinds of satellite remote sensing imagery, complemented by ground reference data obtained by field survey or comparison with existing statistics/maps. These datasets can be used for:

- Estimating spatial distribution of land use. Conventional inventories usually provide only the total sum of land-use area by classes. Spatial distribution can be reconstructed using international land-use and land-cover data as auxiliary data where national data are not available.
- Reliability assessment of the existing land-use datasets. Comparison between independent national and international datasets can indicate apparent discrepancies and understanding these may increase confidence in national data and/or improve the usability of the international data if required for purposes such as extrapolation.

When using an international dataset, it is *good practice* to consider the following:

- The classification scheme (e.g., definition of land-use classes and their relations) may differ from that in the national system. The equivalence between the classification systems used by the country and the systems described in Section 2.2 (Land-Use Categories) therefore needs to be established by contacting the international agency and comparing their definitions with those used nationally.
- Spatial resolution (typically 1km nominally but sometimes an order of magnitude more in practice) may be coarse, so national data may need aggregating to improve comparability.
- Classification accuracy and errors in geo-referencing may exist, though several accuracy tests are usually conducted at sample sites. The agencies responsible should have details on classification issues and tests undertaken.
- As with national data, interpolation or extrapolation will probably be needed to develop estimates for the time periods to match the dates required for reporting to the UNFCCC or under the Kyoto Protocol.

[7] Raster data means information stored on a regular grid of points, as opposed to polygon data, which is information stored as the coordinates of an outline area sharing a common attribute.

2.4.2 Collection of New Data by Sampling Methods

Sampling techniques for estimating areas and area changes are applied in situations where total tallies by direct measurements in the field or assessments by remote sensing techniques are not feasible or would give inaccurate results. It is *good practice* to apply sampling concepts that are based on sampling set out in Section 3 of Chapter 5, and thus allow for estimation procedures that are consistent and unbiased and result in estimates that are precise.

As discussed in Section 3 of Chapter 5, *good practice* on sampling usually involves a set of sampling units that are located on a regular grid within the inventory area. A land-use class is then assigned to each sampling unit. Sampling units can be used to derive the proportions of land-use categories within the inventory area. Multiplying the proportions by the total area provides estimates of the area of each land-use category. Where the total area is not known it is assumed that each sampling unit represents a specific area. The area of the land-use category can then be estimated via the number of sampling units that fall into this category.

Where sampling for areas is repeated at successive occasions, area changes over time can be derived to construct land-use change matrices.

Applying a sample-based approach for area assessment enables the calculation of sampling errors and confidence intervals that quantify the reliability of the area estimates in each category. It is *good practice* to use the confidence interval to verify if observed category area changes are statistically significant and reflect meaningful changes.

2.4.3 Collection of New Data in Complete Inventories

A complete inventory of land use of all areas in a country will entail obtaining maps of land use throughout the country at regular intervals.

This can be achieved by using remote sensing techniques. As outlined under Approach 3 (Section 2.3.2.3), the data will be most easily used in a GIS based on a set of grid cells or polygons supported by ground truth data needed to achieve unbiased interpretation. If the resolution of these data is sufficiently fine then they may allow direct use for Kyoto Protocol reporting of relevant activities. Coarser scale data could be used to build Approach 1 or 2 data for the whole country or appropriate regions.

A complete inventory could also be achieved by surveying all landowners and each would need to provide suitable data where they own many different blocks of land. Inherent problems in the method include obtaining data at scales smaller than the size of the owner's land as well as difficulties with ensuring complete coverage with no overlaps.

2.4.4 Tools for Data Collection

2.4.4.1 REMOTE SENSING (RS) TECHNIQUES

Remotely sensed data, as discussed here, are those acquired by sensors (optical or radar) on board satellites, or by cameras equipped with optical or infrared films, installed in aircraft. These data are usually classified to provide estimates of the land cover and its corresponding area, and usually require ground survey data to provide an estimate of the classification accuracy. Classification can be done either by visual analysis of the imagery or photographs, or by digital (computer-based) methods. The strengths of remote sensing come from its ability to provide spatially explicit information and repeated coverage including the possibility of covering large areas as well as remote areas that are difficult to access otherwise. Archives of past remote sensing data also span several decades and can therefore be used to reconstruct past time series of land cover and land use. The challenge of remote sensing is related to the problem of interpretation: the images need to be translated into meaningful information on land use and land management. Depending on the satellite sensor, the acquisition of data may be impaired by the presence of atmospheric clouds and haze. Another concern, particularly when comparing data over long time periods, is that remote sensing systems may change. Remote sensing is mainly useful for obtaining area estimates of land-cover/use categories and for assisting in the identification of relatively homogeneous areas that can guide the selection of sampling schemes and the number of samples to be collected. For additional information on remote sensing and spatial statistics, see Cressie (1993) and Lillesand *et a*l (1999).

Types of remote sensing data

The most important types of RS data are 1) aerial photographs, 2) satellite imagery using visible and/or near-infrared bands, and 3) satellite or airborne radar imagery (see Table 5.7.2 for features of main remote sensing platforms). Combinations of different types of remote sensing data (e.g., visible/infrared and radar; different spatial or spectral resolutions) might very well be used for assessing different land-use categories or regions. A complete remote sensing system for tracking land-use change could include many sensor and data type combinations at a variety of resolutions.

Important criteria for selecting remote sensing data and products are:

- Adequate land-use classification scheme;
- Appropriate spatial resolution (The smallest spatial unit for assessing land-use changes under the Kyoto Protocol is 0.05 ha);
- Appropriate temporal resolution for estimating of land-use and carbon stock changes;
- Availability of accuracy assessment;
- Transparent methods applied in data acquisition and processing; and
- Consistency and availability over time.

1. Aerial photographs

Analysis of aerial photographs can reveal forest tree species and forest structure from which relative age distribution and tree health (e.g., needle loss in coniferous forests, leaf loss and stress in deciduous forests) may be inferred. In agriculture analysis, RS can show crop species, crop stress, and tree cover in agro-forestry systems. The smallest spatial unit possible to assess depends on the type of aerial photos used, but for standard products it is often as small as 1 square metre.

2. Satellite images in visible and near infrared wavelengths

Complete land use or land cover of large areas (national or regional), if not available otherwise, may be facilitated by the use of satellite images. The possibility exists of obtaining long time series of data from the desired area since the satellite continuously and regularly passes over it. The images usually generate a detailed mosaic of distinct categories, but the labelling into proper land-cover/use categories commonly requires ground reference data from maps or field surveys. The smallest unit to be identified depends on the spatial resolution of the sensor and the scale of work. The most common sensor systems have a spatial resolution of 20 – 30 metres. At a spatial resolution of 30 metres, for example, units as small as 1ha can be identified. Data from higher resolution satellites is also available.

3. Radar imagery

The most common type of radar data are from the so-called Synthetic Aperture Radar (SAR) systems that operate at microwave frequencies. A major advantage of such systems is that they can penetrate clouds and haze, and acquire data during night-time. They may therefore be the only reliable source of remote sensing data in many areas of the world with quasi-permanent cloud cover. By using different parts of the spectrum and different polarisations, SAR systems may be able to distinguish land-cover categories (e.g., forest/non-forest), or the biomass content of vegetation, although there are at present some limitations at high biomass due to signal saturation.

Ground reference data

In order to make use of remote sensing data for inventories, and in particular to relate land cover to land use it is *good practice* to complement the remotely sensed data with ground reference data (often called ground truth data). Ground reference data can either be collected independently, or be obtained from forest or agricultural inventories. Land uses that are rapidly changing over the estimation period or that have vegetation cover known to be easily misclassified should be more intensively ground-truthed than other areas. This can only be done by using ground reference data, preferably from actual ground surveys collected independently but high-resolution photographs may also be useful.

Integration of remote sensing and GIS

Visual interpretation of images is often used for identifying sampling sites for forestry inventories. The method is simple, and reliable. However, it is labour intensive and therefore restricted to limited areas, and may be affected by subjective interpretations by different operators.

Full use of remote sensing generally requires integration of the extensive coverage that remote sensing can provide with ground-based point measurements or map data to represent areas associated with particular land uses in space and time. This is generally achieved most cost effectively using a geographical information system (GIS).

Land-cover classification using remotely sensed data

Classification of land cover using remotely sensed data may be done by visual or digital (computer based) analysis. Each one presents advantages and disadvantages. Visual analysis of imagery allows for human inference through the evaluation of overall characteristics of the scene (analysis of the contextual aspects in the image). Digital classification, on the other hand, allows several manipulations to be performed with the data, such as merging of different spectral data, which can help to improve modelling of the biophysical ground data (such as tree diameter, height, basal area, biomass) using the remotely sensed data. In addition, digital analysis allows for the immediate computation of areas associated with the different land categories. It has developed rapidly over the past decade, along with the associated technical computer development, making hardware, software and also the satellite data readily available at low cost in most countries, although capacity to use these data and facilities may have to be outsourced, particularly in mapping at national level.

Detection of land use change using RS

Remote sensing can be used to detect locations of change related to LULUCF. Methods for land-use change detection can be divided into two categories (Singh (1989)):

Post-classification change detection: This refers to techniques where two or more predefined land-cover/use classifications exist from different points in time, and where the changes are detected, usually by subtraction of the datasets. The techniques are straightforward but are also very sensitive to inconsistencies in interpretation and classification of the land categories.

Pre-classification change detection: This refers to more sophisticated and biophysical approaches to change detection. Differences between spectral response data from two or more points in time are compared by statistical methods and these differences are used to provide information on land-cover/use changes. This approach is less sensitive to interpretation inconsistencies and can detect much more subtle changes than the post-classification approaches, but is less straightforward and requires access to the original remote sensing data.

Evaluation of mapping accuracy

Whenever a map of land cover/use is being used, it is *good practice* to acquire information about the reliability of the map. When such maps are generated from classification of remote sensing data, it should be recognised that the reliability of the map is likely to vary between the different land categories. Some categories may be uniquely distinguished while others may easily be confounded with others. For example, coniferous forest is often more accurately classified than deciduous forest because its reflectance characteristics are more distinct, while deciduous forest may easily be confounded with, for example, grassland or cropland. Similarly, it is often difficult to ascertain changes in land management practices through remote sensing. For example, it may be difficult to detect a change from conventional to conservation tillage on a specific land area.

It is therefore *good practice* to estimate the accuracy of land-use/land-cover maps on a category-by-category basis. A number of sample points on the map and their corresponding real world categories are used to create a confusion matrix (See Approach 3; Footnote 6) with the diagonal showing the probability of correct identification and the off-diagonal elements showing the relative probability of misclassification of a land category into one of the other possible categories. The confusion matrix expresses not only the accuracy of the map but it is also possible to determine which categories are easily confounded with each other. Based on the confusion matrix, a number of accuracy indices can be derived (Congalton, 1991). It is *good practice* to present an estimate of the accuracy of the land-use/cover map category-by-category and a confusion matrix may be employed for this purpose where remote sensing is used. Multi-temporal analysis (analysis of images taken at different times to determine the stability of land-use classification) can also be used to improve classification accuracy, particularly in cases where ground truth data are limited.

2.4.4.2 GROUND-BASED SURVEYS

Ground-based surveys may be used to gather and record information on land use, and for use as independent ground-truth data for remote sensing classification. Prior to the advent of remote sensing techniques such as aerial photography and satellite imagery, ground-based surveys were the only means of generating maps. The process is essentially one of visiting the area under study and recording visible and/or other physical attributes of the landscape for mapping purposes. Digitisation of boundaries and symbolising attributes are used to make hard copy field notes and historical maps useful in Geographic Information Systems (GIS). This is done via protocols on minimum land area delineation and attribute categorisation that are linked to the scale of the resultant map and its intended use.

Very precise measurements of area and location can be made using a combination of survey equipment such as theodolites, tape measures, distance wheels and electronic distance measuring devices. Development of Global Positioning Systems (GPS) means that location information can be recorded in the field directly into electronic format using portable computer devices. Data are downloaded to an office computer for registration and coordination with other layers of information for spatial analysis.

Landowner interviews and questionnaires are used to collect socio-economic and land management information, but may also provide data on land use and land-use change. With this census approach, the data collection agency depends on the knowledge and records of landowners (or users) to provide reliable data. Typically, the resident is visited and interviewed by a representative of the collection agency and data are recorded in a predetermined format, or a questionnaire is issued to the land-user for completion. The respondent is usually encouraged to use any relevant records or maps they may have, but questions may also be used to elicit information directly (Swanson *et al*., 1997).

Census surveys are probably the oldest form of data collection methods (Darby, 1970). Land-user surveys can be conducted on the entire population or a sample of suitable size. Modern applications employ a full range of validation and accuracy assessment techniques. The survey may be undertaken through personal visits, telephone interviews (often with computer-assisted prompts) or mail-out questionnaires. Land-user surveys start with the formulation of data and information needs into a series of simple and clear questions soliciting concise and unequivocal responses. The questions are tested on a sample of the population in order to ensure that they are understandable and to identify any local technical terminology variations. For sample applications, the entire study area is spatially stratified by appropriate ecological and/or administrative land units, and by significant categorical differences within the population (e.g., private versus corporate, large versus small, pulp versus lumber, etc.). For responses dealing with land areas and management practices, some geographic location, whether precise coordinates, cadastral description or at least ecological or administrative units should be required of the respondent. Post-survey validation of results is conducted by searching for statistical anomalies, comparing with independent data sources, conducting a sample of follow-up verification questionnaires or conducting a sample of on-site verification surveys. Finally, presentation of results must follow the initial stratification parameters.

Annex 2A.1 Examples of Approaches in individual countries

2A.1.1 Use of Existing Resource Inventories by USA (Approaches 1, 2 and 3)

In the United States, the National Resources Inventory (NRI) is designed to assess soil, water, and related environmental resources on non-Federal lands (Nusser and Goebel, 1997; Fuller, 1999)[8]. The NRI uses data from several sources to verify estimates. A Geographic Information System (GIS) for the United States is used to hold the inventory and includes the total surface area, water area, and Federal land. Data from other sources e.g., soils databases and other inventories such as the Forest Inventory and Analysis (FIA), can be linked to the NRI[9]. While sampling techniques for the NRI and FIA are similar, differing objectives require different sampling grids and make the estimates from the two inventory systems statistically independent. The raw sampled data could, however, be used as a basis for Approach 3.

The data (See Table 2A.1.1) are sufficient to provide a land-use change matrix (Approach 2) that illustrates several important land use and land-use change characteristics for the United States. First, comparing the 1997 total to the 1992 total for each of the broad land-use categories depicts the net change in land use. For example, the amount of cropland declined by 2.1 million hectares from 1992 to1997, falling from 154.7 million hectares to 152.6 million hectares, while the amount of non-Federally owned range and forests remained relatively stable. These aspects of land use could also have been seen from an Approach 1 database. In addition, the total area of the United States remains fixed from 1992 to 1997 at almost 800 million hectares, and thus any area increases in a one land-use category must be offset by area declines in other categories as could have been provided in an Approach 2 structure.

However, the data can also describe land-use change dynamics using its Approach 2 structure. The diagonal and off-diagonal elements in Table 2A.1.1 show how much land has remained in a land category and how much land has changed use respectively. Comprehensive measures of changes in land use (the off-diagonal elements) can be extremely important for carbon estimation and reporting. For example, the total amount of non-Federal forest land remained relatively stable from 1992 to1997, increasing by about 400 000 hectares. However, the land-use change elements show that 1.9 million hectares of non-Federal forest land were converted to settlements while 2.5 million hectares of pastureland were converted to forest land. Therefore, inferring small changes in carbon stock based on small changes in overall land use could be incorrect if the individual land-use dynamics (e.g., Forest land to settlements and pastureland to forests) are relatively large.

TABLE 2A.1.1
LAND USE AND LAND-USE CHANGE MATRIX FOR USA

Initial \ Final	Crop	CRP	Pasture	Range (NF)	Forest (NF)	Other Rural	Settle-ments	Water and Federal	1997 Total
Crop	146.8	0.9	3.5	0.8	0.3	0.3	--	--	152.6
CRP	0.8	12.3	--	--	--	--	--	--	13.2
Pasture	3.7	0.3	43.2	0.3	0.8	0.3	--	--	48.6
Range (NF)	0.6	0.1	0.6	162.3	0.5	0.2	--	--	164.4
Forest (NF)	0.8	--	2.5	0.6	160.1	0.6	--	--	164.5
Other Rural	0.7	--	0.4	0.3	0.4	18.9	--	--	20.7
Settlements	1.2	--	0.8	0.5	1.9	0.2	35.2	--	39.8
Water and Federal Land	0.1	--	--	0.1	0.2	--	--	182.6	183.1
1992 Total	154.7	13.8	51.0	165	164.1	20.5	35.2	182.8	787.4

Note: (i) Data from the 1997 NRI and excludes Alaska. (ii) NF is Non-Federal. Areas are millions of hectares. (iii) CRP represents land enrolled in the Conservation Reserve Program. (iv) Some row and column totals do not add up due to rounding errors.

[8] The NRI is conducted by the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service, in cooperation with the Iowa State University Statistical Laboratory. More information on the NRI is found at: http://www.nhq.nrcs.usda.gov/technical/NRI/1997/.

[9] The FIA is managed by the Research and Development organization within the USDA Forest Service in cooperation with State and Private Forestry and National Forest Systems. More information on the FIA is found at: http://fia.fs.fed.us/.

2A.1.2 Use of Agricultural Data for the Argentine Pampas (Approaches 1 and 2)

Since 1881, various national agricultural censuses involving 100% of farms in the Argentine pampas have been undertaken. Data on land use were organized at the level of political districts in each of the 24 provinces. A particular study on land-use change in the pampas across one century of agricultural transformation was recently published (Viglizzo *et al*., 2001). Later results show that the Argentine pampas behaved as a net source of greenhouse gas emitter over much of the period in response to the conversion of natural grasslands into grazing lands and croplands. However, emissions tend to decline since 1960 due to the adoption of conservation soil management techniques, mainly reduced- and no-tillage methods - (Bernardos *et al*., 2001).These data can be used in the implementation of Approach 1 or 2.

2A.1.3 Use of Land Registry Data in China (Approach 1)

China uses Approaches 1 and 2 for land-use change data, including forest inventories every 5 years, agricultural censuses and other surveys. In particular, China is implementing a household contract system for returning cultivated land to woodland. An individual contract system is being introduced whereby households are assigned tasks, receive subsidies and own the trees and other vegetation that they plant. The programme aims at planting about 5 million hectares with trees from year 2000 to 2010. The contracts for this scheme have been used to make a database of specific land-use changes.

2A.1.4 Land-use Matrices in the United Kingdom (Approaches 1, 2 and 3)

In the United Kingdom, land-use change matrices have been constructed from field survey data (Barr *et al*. 1993, Haines-Young, 2000). Three surveys have now been completed, in 1984, 1990 and 1998. Each sample was a 1 km square area and 384 of these were used in 1984 to provide a stratified sampling of 32 eco-climatic zones. These sample squares were revisited in 1990 and 1998 and about another 140 were added for the campaign in 1990 and another 50 for 1998 to improve the coverage of the eco-climatic zones. Initially land-use /cover classes unique to the survey were developed, but in 1998 alternative types common to other agencies in the UK were used. The saved data for 1984 and 1990 have now been reclassified into the new classes. Each 1 km sample was visited by surveyors who, starting from existing 1:10 560 maps, drew outlines of different land cover/use parcels, numbered the parcels and recorded a range of information for each parcel. Subsequently, the maps were digitised and the area of each parcel calculated from the digital data. When a square was revisited some years later, the digitised maps, with the older parcel boundaries, became the starting point for recording of changes in the parcels. Thus data were built up, not only of the areas of land-cover/use classes in each sampling year, but of the transitions occurring between each class. Regional and national estimates of land cover/use and change were then made by weighted averaging of the samples against the occurrence in the different eco-climatic zones.

LUC matrices for England, Scotland and Wales between 1984 and 1990 were constructed for a simplified set of land-use categories (Farm, Natural, Urban, Woods, Other) and have been used for estimating emissions and removals for Category 5D (CO_2 emissions and uptake by soils from LUC and management) of the UK greenhouse gas inventory. An example is shown in Table 2A.1.2.

TABLE 2A.1.2
LAND-USE CHANGE MATRIX FOR SCOTLAND BETWEEN 1984 AND 1990

1990 / 1984	Farm	Natural	Urban	Woods	Other	1990 Total
Farm	1 967	81	6	6	0	2 060
Natural	113	4 779	5	32	0	4 929
Urban	14	4	276	1	0	2 95
Woods	9	77	1	981	0	1 068
Other	0	0	0	0	141	141
1984 Total	2 103	4 941	288	1 020	141	8 493

Note: Areas are thousands of hectares

The uncertainty in estimating land use and land-use change for regions using this method of sampling has been described by Barr *et al*. (1993). If the variation in land use or change across a region is known or can be estimated by an approximate value then the number of samples needed for a specified level of confidence in the regional total area for that land use or change can be estimated from statistical theory (Cochran, 1977).

2A.1.5 The New Zealand Example of Implementation of Land-Use/Cover Database from Remote Sensing (Approach 3)

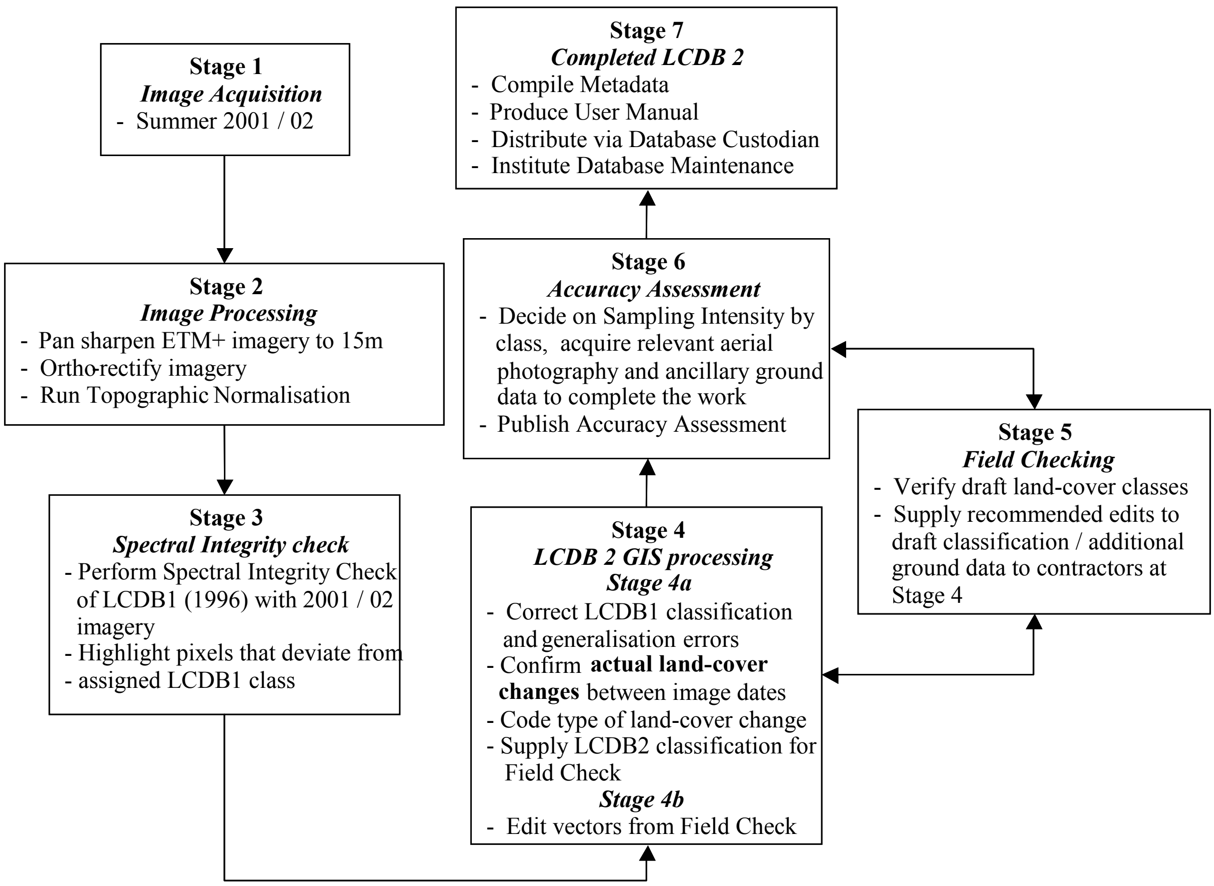
The first New Zealand land-use /Cover Database (NZLCDB) was completed in June 2000 from satellite images acquired, mainly during the summer of 1996/97. For New Zealand, an appropriate period of time for detecting significant land-cover changes is considered to be five years. Landsat Enhanced Thematic Mapper Plus (7 ETM+) is the preferred sensor with in-fill from *Système Probatoire d'Observation de la Terre* (SPOT) as necessary. Work commenced in 2001/02 on image acquisition and analyses, which will continue through until 2003/04 to produce NZLCDB2, following stages outlined below.

The cost of Land-Cover Database 2 (NZLCDB2) is of the order of US$1 500 000 for 270 000 km^2 i.e., US$5.6 per km^2 and it will provide:

- A complete set of multi-spectral and ortho-corrected satellite imagery covering New Zealand sharpened to 15m spatial resolution;
- A revised NZLCDB1 digital GIS map of land-cover classes with identified classification and generalisation errors corrected;
- A new NZLCDB2 digital GIS map of land-cover classes compatible with NZLCDB1 "parent classes";
- A digital GIS map recording changes identified in land cover for New Zealand at the 1 ha minimum mapping unit, and
- An accuracy assessment of NZLCDB2 including an error matrix to estimate data quality both spatially and by class.

A fuller description of the New Zealand Land-Cover Database project, which will be updated as the project progresses, can be found at http://www.mfe.govt.nz/issues/land/land-cover-dbase/index.html. The stages of completion of the database are shown in Figure 2A.1.1.

Figure 2A.1.1 Stages in preparation of New Zealand Land-Cover Databases



2A.1.6 The Australian Multi-Temporal Landsat Database for Carbon Accounting (Approach 3)

The Australian Greenhouse Office (AGO) through its National Carbon Accounting System (NCAS) has developed a national scale multi-temporal remote sensing programme which is an example of Approach 3, even though its primary purpose is to identify areas of land impacted by forest cover change rather than full land-use mapping. Using Landsat satellite data for twelve national passes between 1972 and 2002, the forest cover status of land units is monitored over time, at better than a one-hectare resolution. Initially a Year 2000 mosaic of scenes was constructed for the whole continent (369 scenes) as a base dataset to which other time series were registered.

Consistent geographic resolution and spectral calibration of satellite data allows for objective statistical analysis on a single land unit (pixel) through time. Remote sensing experts experienced in interpreting the Australian vegetation developed the analytical methods (Furby, 2002) that were refined over two rounds of pilot testing (Furby and Woodgate, 2002). The pilot testing was also used to train private sector providers who subsequently competitively bid for the work.

In addition to the highly prescriptive methodology and performance standards, an independent quality assurance programme has been implemented to ensure a consistent output standard. A Continuous Improvement and Verification Programme also monitors the quality of results and provides guidance on future improvements. Because the methodology uses a conditional probability approach, the full time series is readily subjected to any improvements identified.

The efficiency in processing methods developed for the programme has enabled the addition of new national passes to the time series at a cost of approximately half a million US dollars.

The forest cover change data is integrated into a carbon/nitrogen cycle process model which is spatially operated from within a Geographic Information System. In this way, carbon accounting of this sector is readily accomplished.

Further information can be found in various NCAS Technical Reports available on the AGO Website: http://www.greenhouse.gov.au/ncas.

ANNEX 2A.2 Examples of international land cover datasets

EXAMPLES OF INTERNATIONAL LAND COVER DATASETS				
Dataset name	AARS Global 4-Minute Land Cover	IGBP-DIS Global 1km Land Cover Data Set	Global Land Cover Dataset	Global Land Cover Dataset
Author	Center for Environmental Remote Sensing, Chiba University	IGBP/DIS	USGS, USA	GLCF (Global Land Cover Facility)
Brief description of contents	Land cover classes are identified through clustering NOAA AVHRR monthly data.	This classification is derived from Advanced Very High Resolution Radiometer (AVHRR) 1km data and ancillary data.	The data set is derived from a flexible data base structure and seasonal land-cover regions concepts	Metrics describing the temporal dynamics of vegetation were applied to 1984 PAL data at 8km resolution to derive a global land-cover classification product using a decision tree classifier.
Classification scheme	Original classification scheme is applied. Compatible with IGBP/DIS classification scheme.	It consists of 17 classes.	A convergence of evidence approach is used to determine the land cover type for each seasonal land cover class.	The classification was derived by testing several metrics that describe the temporal dynamics of vegetation over an annual cycle.
Data format (vector/raster)	Raster	Raster	Raster	Raster
Spatial coverage	Global	Global	Global	Global
Data acquisition year	1990	1992-1993	April 1992-March 1993	1987
Spatial resolution or grid size	4min x 4min.	1km x 1km	1km x 1km	8km x 8km
Revision interval (for time-series datasets)	Not applicable	Not applicable	Not applicable	Not applicable
Quality description	Ground truth data are compared against the dataset.	High-resolution satellite imagery used to statistically validate the dataset.	Sample point accuracy: 59.4% Area-weighted accuracy: 66.9% (Scepan, 1999).	No description
Contact address and reference URL	tateishi@rsirc.cr.chiba-u.ac.jp http://ceres.cr.chiba-u.ac.jp:8080/usr-dir/you/ICHP/index.html	alan.belward@jrc.it http://www.ngdc.noaa.gov/paleo/igbp-dis/frame/coreprojects/index.html	icac@usgs.govhttp://edcdaac.usgs.gov/glcc/globe_int.html.	http://glcf.umiacs.umd.edu/data.html

Examples of international land cover datasets (Continued)				
Dataset name	1º Land Cover Map from AVHRR	CORINE land cover (CLC) database	Digital Chart of the World	Global Map
Author	Dr. Ruth DeFries University of Maryland at College Park, USA	European Environmental Agency	ESRI Products	Produced by National Mapping Organizations, and Compiled by ISCGM.
Brief description of contents	The data set describes the geographical distributions of eleven major cover types based on inter-annual variations in NDVI.	It provides a pan-European inventory of biophysical land cover. CORINE land cover is a key database for integrated environmental assessment.	It is a worldwide base map of coastlines, boundaries, land cover, etc. Contains more than 200 attributes arranged into 17 thematic layers with text annotations for geographical features.	Digital geographic information in 1 km resolution covering the whole land with standardized specifications and available to everyone at marginal cost.
Classification scheme	It consists of the digital 13 class map	Uses a 44 class nomenclature.	8 Agriculture/ Extraction features and 7 surface cover features.	Refer to http://www.iscgm.org/gm-specifications11.pdf
Data format (vector/raster)	Raster	Raster	Vector Polygons	Raster and Vector
Spatial coverage	Global	Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland , Portugal, Romania, Slovakia, Spain, United Kingdom, Parts of Morocco and Tunisia.	Global coverage	Participating countries (90 in number)
Data acquisition year	1987	Depends on the country (overall time span is around 1985-95)	Based on ONCs of US Defense Mapping Agency. Period 1970-80. Refer to the Compilation date layer.	Depends on the participating nations.
Spatial resolution or grid size	1 x 1 degree	250m by 250m grid database which has been aggregated from the original vector data at 1:100,000.	1:1,000,000 scale	1km x 1km grids
Revision interval (for time-series datasets)	Not applicable	CLC Update Project of 2000 for updating it to the 1990's data	Not applicable	Approximately five-year intervals
Quality description	No description	No specific information available. Refer to http://dataservice.eea.eu.int/dataservice/other/land_cover/lcsource.asp for country wise information.	Data quality information exists at three levels within the database: feature, layer and source.	Refer to http://www.iscgm.org/gm-specifications11.pdf.
Contact address and reference URL	landcov@geog.umd.edu http://www.geog.umd.edu/landcover/1d-map.html	dataservice@eea.eu.int http://dataservice.eea.eu.int/dataservice/metadetails.asp?table=landcover and i=1	http://www.esri.com/data/index.html	sec@iscgm.org http://www.iscgm.org/

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