# CHAPTER 8

# SETTLEMENTS

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## 8.1 INTRODUCTION

This Chapter provides methods for estimating carbon stock changes and greenhouse gas emissions and removals associated with changes in biomass, dead organic matter (DOM), and soil carbon on lands classified as settlements. Settlements are defined in Chapter 3 as including all developed land -- i.e., residential, transportation, commercial, and production (commercial, manufacturing) infrastructure of any size, unless it is already included under other land-use categories. The land-use category Settlements includes soils, herbaceous perennial vegetation such as turf grass and garden plants, trees in rural settlements, homestead gardens and urban areas. Examples of settlements include land along streets, in residential (rural and urban) and commercial lawns, in public and private gardens, in golf courses and athletic fields, and in parks, provided such land is functionally or administratively associated with particular cities, villages or other settlement types and is not accounted for in another land-use category. See Chapter 3 for area reporting guidelines and for definitions of the six land-use categories.

Roughly 2% of Earth's terrestrial surface is covered by urban areas which are home to over 3 billion people. Over half of the world population currently lives in cities; this number is projected to double within 50 years (Crane and Kinzig, 2005). In many regions, land classified as urban, based on population density or city boundaries, is just a subset of land that can be classified as settlements using the criteria described above. These areas of less-dense settlement may extend well beyond the officially-defined border of a city, and in many regions their areas are expanding quickly (Elvidge *et al*., 2004; Gallo *et al*., 2004; Theobald, 2004). In areas that are primarily rural, even if land uses are not changing quickly, land devoted to residential uses can occupy a significant portion of the landscape. Transitions of Forest Land, Cropland, and Grassland to Settlements can have important impacts on carbon stocks and fluxes (Imhoff *et al*., 2000; Milesi *et al*., 2003).

Vegetation management in settlements may result in gains, losses, or transfers of carbon amongst the relevant pools. For example, branches removed during pruning or turfgrass clippings (biomass losses) may be left on site (transfer to litter), disposed of as solid waste (transfer to waste), or burned (emitted). Emissions of the relevant greenhouse gases are accounted for in the appropriate sections of the present guidance. For example, Table 2.3 in Chapter 2, Volume 5 (Waste), includes wood/ yard waste in national-scale statistics describing the fate of municipal solid waste at the national scale. Biomass removed as fuelwood from trees in settlements and used as fuel is accounted for in the Energy Sector. The net effect of conversion or management leading to increment, on the one hand, or to loss (such as from burning and decay), on the other, determines the overall C balance in settlements.

Soils and DOM in *Settlements Remaining Settlements* or in *Land Converted to Settlements* may be sources or sinks of $CO_2$, depending on previous land use, topsoil burial or removal during development, current management, particularly with respect to nutrient and water applications, and the type and amount of vegetation cover interspersed among roads, buildings and associated infrastructure (Goldman *et al*., 1995; Jo, 2002; Pouyat *et al*., 2002; Qian and Follett, 2002; Kaye *et al*., 2004; Kaye *et al*., 2005).

The *1996 IPCC Guidelines* covered above-ground biomass in trees in rural settlements, but not other settlement categories and pools.

The *2006 IPCC Guidelines* differ from those in the *GPG-LULUCF* as follows:

- The discussion and detailed methodologies have been moved from the Appendix to the main text and considered as greenhouse gas emission source or removal sector;
- The discussion and methodologies have been expanded to include the five biomass pools described in Chapter 1;
- Tier 1 default methodologies are presented;
- Additional data appropriate for Tiers 2 and 3 have been published since the *GPG-LULUCF* and are included here; and
- An expanded discussion on developing and applying country-specific Tier 2 and Tier 3 methodologies and values is included, including methods to work with more detailed activity data.

The carbon pools estimated for Settlements are above-ground and below-ground biomass, DOM, and soils. Sections 8.2 and 8.3 respectively describe methodology to estimate changes in carbon stocks for *Settlements Remaining Settlements*, and to estimate carbon stocks on *Land Converted to Settlements*. The methodology in the second section is broadly applicable to *Land Converted to Settlements* from any other type of land.

# 8.2 SETTLEMENTS REMAINING SETTLEMENTS

This category refers to all classes of urban formations that have been in use as settlements (e.g., areas that are functionally or administratively associated with public or private land in cities, villages, or other settlement types), since the last time data were collected. Emissions and removals of $CO_2$ in this category are estimated by the subcategories of changes in carbon stocks in biomass (both woody and perennial non-woody components), in DOM, and in soils, as summarized in Equation 2.3 in Chapter 2.

The biomass pool in settlements has woody and herbaceous components. For woody biomass, carbon stock change is calculated as the difference between biomass increment and biomass loss due to management activities. For herbaceous biomass (such as turfgrass or garden plants) in *Settlements Remaining Settlements*, the carbon stock change in biomass can usually be assumed to be zero.

The DOM pool in settlements contains dead wood and litter from both woody and herbaceous components. For the woody vegetation, changes in this pool can be quantified as production of coarse and fine litter from woody plants. For herbaceous vegetation, annual production of DOM is estimated as the accumulation of thatch plus production of herbaceous material such as garden waste and yard trimmings. Greenhouse gas emissions associated with Waste Sector are estimated in Volume 5 (Waste) and therefore the methods in this Chapter describe only those components of annual production that can reasonably be expected to stay on-site.

Soil C pools vary with time depending on the balance between C inputs from plant litter and other forms of organic matter and C outputs resulting from decomposition, erosion and leaching. Estimating the impact of settlement management on soil C storage will be particularly important in countries with a large portion of land in cities and towns, or high rates of settlement expansion. For mineral soils, the impact of settlement land use and management on soil C stocks can be estimated based on differences in storage among settlement cover classes relative to a reference condition, such as native lands. Although organic soils are less commonly used for settlements, C is emitted from these soils if they are drained for development due to enhanced decomposition, similar to the effect of drainage for agricultural purposes (Armentano, 1986). In addition, peat may be harvested from organic soils during settlement development, which will also generate emissions to the atmosphere.

## 8.2.1 Biomass

### 8.2.1.1 CHOICE OF METHOD

The general method for biomass carbon stock change in *Settlements Remaining Settlements* follows the approach in Equation 2.7 in Chapter 2. This method estimates changes in biomass carbon stocks, accounting for gains in carbon stocks in biomass as a result of growth minus losses in carbon stocks as a result of pruning and mortality. Depending on the relative magnitudes of the increment and loss terms, the average annual changes in biomass carbon stocks in settlements may be positive or negative.

Biomass change in *Settlements Remaining Settlements* is the sum of biomass change in three components: trees, shrubs, and herbaceous perennials (e.g., turfgrass and garden plants), as described in Equation 8.1.

**EQUATION 8.1**
**ANNUAL CARBON CHANGE IN LIVE BIOMASS POOLS IN SETTLEMENTS REMAINING SETTLEMENTS**

$$\Delta C_B = \Delta C_{Trees} + \Delta C_{Shrubs} + \Delta C_{Herbs}$$

Where:

$\Delta C_B$ = annual carbon accumulation attributed to biomass increment in *Settlements Remaining Settlements*, tonnes C $yr^{-1}$

$\Delta C_{Trees}$ = annual carbon accumulation attributed to biomass increment in trees in *Settlements Remaining Settlements*, tonnes C $yr^{-1}$

$\Delta C_{Shrubs}$ = annual carbon accumulation attributed to biomass increment in shrubs in *Settlements Remaining Settlements*, tonnes C $yr^{-1}$

$\Delta C_{Herbs}$ = annual carbon accumulation attributed to biomass increment in herbaceous biomass in *Settlements Remaining Settlements*, tonnes C $yr^{-1}$

Depending on the availability of relevant activity data and appropriate emission factors, any of the methodological tiers described below can be used. Figure 2.2 in Chapter 2 also provides guidance for the identification of the appropriate tier to estimate changes in carbon in biomass.

**Tier 1**

Tier 1 assumes no change in carbon stocks in live biomass in *Settlements Remaining Settlements*, in other words, that the growth and loss terms balance. If the category *Settlements Remaining Settlements* is determined to be a key category, then a country should collect appropriate activity data and/or develop emission factors appropriate to the region and adopt Tier 2 or 3.

**Tier 2**

There are two options for Tier 2 estimation of changes in biomass in *Settlements Remaining Settlements*. Tier 2a uses changes in carbon stocks per unit of plant crown cover area as a removal factor, and Tier 2b uses changes in carbon stocks per number of plants as a removal factor. The choice of method will depend on availability of activity data. Tier 2a and Tier 2b both provide methods for estimating $\Delta C_G$ in Equation 2.7 (Gain-Loss Method). This is appropriate for countries lacking a continuous inventory in *Settlements Remaining Settlements*.

The main perennial types are trees, shrubs, and herbaceous perennials (such as turfgrass and garden plants). The methods as presented here set the change in biomass of herbaceous annuals to zero in *Settlements Remaining Settlements* on the basis that growth of herbaceous biomass (whether perennial or annual herbaceous vegetation) is equal to loss from harvest or mortality. Countries may choose to define tree and woody perennial types as appropriate and each types may be further divided into classes defined according to species, climate zone, seasonality, or other criteria as appropriate and if data are available.

**Tier 2a: Crown cover area method**

This method is represented by Equation 8.2 and should be used when data are available on total area of crown cover in perennial types (j) and their classes (i) in *Settlements Remaining Settlements*.

**EQUATION 8.2**
**ANNUAL BIOMASS INCREMENT BASED ON TOTAL CROWN COVER AREA**

$$\Delta C_G = \sum_{i,j} AT_{i,j} \bullet CRW_{i,j}$$

Where:

$\Delta C_G$ = annual carbon accumulation attributed to biomass increment in *Settlements Remaining Settlements*, tonnes C $yr^{-1}$

$AT_{ij}$ = total crown cover area of class *i* in woody perennial[1] type *j*, ha

$CRW_{ij}$ = crown cover area-based growth rate of class *i* in woody perennial type *j*, tonnes C (ha crown cover)$^{-1}$ $yr^{-1}$

**Tier 2b: Individual plant[2] growth method**

The method is represented by Equation 8.3 and should be used where data on the number of woody plants by broad species class in *Settlements Remaining Settlements* are available. It is possible, when making estimates for trees, to convert between the methods used in Tiers 2a and 2b by assuming that an individual tree in an urban area covers approximately 50 $m^2$ crown area when mature (cf. Akbari, 2002).

**EQUATION 8.3**
**ANNUAL BIOMASS GROWTH BASED ON NUMBER OF INDIVIDUAL WOODY PLANTS IN BROAD CLASSES**

$$\Delta C_G = \sum_{i,j} NT_{i,j} \bullet C_{i,j}$$

Where:

$\Delta C_G$ = annual carbon accumulation due to live biomass increment in *Settlements Remaining Settlements*, tonnes C $yr^{-1}$

$NT_{ij}$ = number of individuals of class *i* in perennial type *j*

$C_{ij}$ = annual average carbon accumulation per class *i* of perennial type *j*, tonnes C $yr^{-1}$ per individual

1 References to woody perennials include trees unless otherwise specified.

2 References to plants include trees unless otherwise specified.

**Tier 3**

Tier 3 approaches can be based either on Tier 2 methods above (Equations 8.2 and 8.3) with more detailed measurements of parameters at disaggregated level for different settlement systems such as parks, rural or urban residential areas, avenues, etc., or on a stock difference approach based on Equation 2.8. Changes in carbon stocks are estimated at two points in time, where the changes account for biomass carbon gains and losses. The generic approach for this method calls for forest-specific biomass expansion factors (BEFs) which do not apply to settlements. Countries wishing to use the stock difference method to estimate biomass change in *Settlements Remaining Settlements* should consider using allometric methods such as those based on individual tree diameter at breast height (dbh) (Jenkins *et al*., 2004), adjusted for open-grown trees as described above, rather than forest specific BEFs for estimating tree biomass.

### 8.2.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

Few allometric biomass equations exist specifically for trees or shrubs in urban settings (Nowak, 1996; Jo, 2002) so investigators have tended to apply equations derived for forest trees, adjusting the resulting biomass with a coefficient (such as 0.80 [Nowak, 1994; Nowak and Crane, 2002]) intended to take account of the allometry of open-grown trees in cities where above-ground biomass for a given diameter is typically lower than that of forest-grown trees (Nowak, 1996). Allometric equations for some shrub species exist, but have not routinely been applied to urban settings (Smith and Brand, 1983; Nowak *et al*., 2002 for shrub leaf biomass estimates). Below-ground tree biomass can be derived from above-ground biomass by multiplying the latter by an estimated root: shoot ratio, as described by Cairns *et al*. (1997) and applied for urban settings by Nowak *et al*. (2002). See Chapter 4 (Forest Land) for examples of root: shoot ratios (R) (also called below-ground to above-ground biomass ratio) often used in forest settings. Ratios appropriate to the region of interest can be assumed to apply without modification to settlements.

Tree growth and mortality in settlements can be affected by urban conditions such as variations in local air quality, atmospheric deposition, enhanced atmospheric $CO_2$ concentrations, and reduced air exchange in the root zone due to impermeable paving surfaces (e.g., Pouyat *et al*., 1995; Idso *et al*., 1998; Idso *et al*., 2001; Gregg *et al*., 2003; Pouyat and Carreiro, 2003). Therefore, the values and equations used to predict tree growth in settlements at higher tiers should, to the extent feasible, allow for the surrounding environment and the condition of the trees.

Carbon stored in the woody components of trees makes up the largest compartment of standing biomass stocks and annual biomass increment in settlements. Data are still sparse, though availability is increasing. For example, Nowak and Crane (2002) estimated on a citywide basis that the net annual carbon storage by trees in cities in the conterminous USA ranged from 600 to 32,200 tonnes C $yr^{-1}$. Jo (2002) found that the amount of C sequestered annually in three Korean cities varied from 2,900 to 40,300 tonnes. In Australia, Brack (2002) estimated that the amount of C sequestered by trees in Canberra between 2008 and 2012 would be 6,000 tonnes C $yr^{-1}$. Clearly, the estimates depend on the definition and hence extent of the settlement areas being considered.

The variation is less per unit land area; for ten cities in the United States, measurements of C stored in woody biomass ranged from 150 to 940 kg C $ha^{-1}$ $yr^{-1}$ (Nowak and Crane, 2002) and for three Korean cities annual C stored in woody biomass varied from 530 to 800 kg C $ha^{-1}$ $yr^{-1}$ (Jo, 2002). Trees in urban lawns in Colorado (USA) stored 1,590 kg C $ha^{-1}$ $yr^{-1}$ (Kaye *et al*., 2005). There is still less variation in estimates of annual C storage per unit of tree crown cover. Nowak and Crane (2002) found that annual sequestration rates ranged from 0.12 to 0.26 kg C $m^{-2}$ crown cover $yr^{-1}$, while Brack (2002) used a model to estimate that annual sequestration in Canberra between 2008 and 2012 would be 0.27 kg C $m^{-2}$ $yr^{-1}$.

**Tier 1**

This method assumes, probably conservatively, that changes in biomass carbon stocks due to growth in biomass are fully offset by decreases in carbon stocks due to removals (i.e., by harvest, pruning, clipping) from both living and from dead biomass (e.g., fuelwood, broken branches, etc.). Therefore, in a Tier 1 approach $\Delta C_G = \Delta C_L$ and for all plant components, and $\Delta C_B = 0$ in Equation 2.7.

### Tier 2

*Trees*

Tier 2 calls for parameter values for $CRW_{ij}$ (Equation 8.2) and $C_{ij}$ (Equation 8.3). A default removal factor for tree biomass (CRW) of 2.9 tonnes C (ha crown cover)$^{-1}$ yr $^{-1}$ is usually suitable for Tier 2a (see Table 8.1). This estimate is based on a sample of ten US cities, with values that ranged from 1.8 to 3.4 tonnes C (ha crown cover)$^{-1}$ yr$^{-1}$ (Nowak and Crane, 2002). Values appropriate to national circumstances can also be developed. Using Tier 2b, the removal factor is $C_{ij}$. Table 8.2 provides defaults carbon accumulation rates for tree species classes for use at Tier 2b. These estimates are based on various allometric equations and limited field data from urban areas in the USA, and are averages for trees of all sizes (not just mature trees). Tiers 2a and 2b methods provide biomass estimates for total combined above-ground and below-ground woody biomass. If required below-ground biomass can be estimated separately using a root: shoot ratio of 0.26 (Nowak *et al*., 2002).

For Tiers 2a and 2b, the default assumption for $\Delta C_L$ where the average age of the tree population is less than or equal to 20 years is zero. This is based on the assumption that urban trees are net sinks for carbon when they are actively growing and that the active growing period (AGP) is roughly 20 years, depending on tree species, planting density, and location. Thereafter, the method assumes that the accumulation of carbon in biomass slows with age, and thus for trees older than the AGP, increases in biomass carbon are assumed to be offset by losses from pruning and mortality. For trees older than the AGP this is conservatively accounted for by setting $\Delta C_{G_{wood}} = \Delta C_{L_{wood}}$. Countries can define AGP depending on their circumstances.

*Other woody perennial types*

Countries may, for any perennial type, develop their own values for $CRW_{ij}$ (in Equation 8.2) and $C_{ij}$ (in Equation 8.3). A conservative assumption of no change in any of these components (i.e., $CRW_{ij} = 0$ and $C_{ij} = 0$) can also be applied.

Tiers 2a and 2b both assume no change in herbaceous biomass. Using this method, $\Delta C_{G_{Herbs}} = \Delta C_{L_{Herbs}}$ and $\Delta C_B$ is based on the difference between increment and losses in woody biomass only.

### Tier 3

For Tier 3, countries should develop plant type-specific biomass increment factors appropriate to national circumstances. Country-specific parameters and growth equations should be based on the dominant climate zones and particular species composition of the major settlements areas in a country, before making estimates for less extensive settlements. If country-specific biomass increment parameters are developed from estimates of biomass on a dry matter basis, they need conversion to units of carbon using either a default carbon fraction (CF) of 0.5 tonne C (tonne d.m.)$^{-1}$, or a carbon fraction that is more appropriate to circumstances.

Under higher tiers, the assumptions for $\Delta C_L$ should be evaluated and modified to address national circumstances better. For instance, countries may have information on age-dependent and/ or species-specific carbon losses in settlement trees. In this case, countries should develop a loss term and document the resources and rationale used in its development.

If a country adopts the stock-difference method (Equation 2.8), it should have representative sampling and periodic measurement system to estimate the changes in biomass carbon stocks.

**TABLE 8.1**
**TIER 2A DEFAULT CROWN COVER AREA-BASED GROWTH RATES (CRW) FOR URBAN TREE CROWN COVER BY REGION**

| Region | Default annual carbon accumulation per ha tree crown cover [tonnes C (ha crown cover)$^{-1}$ yr$^{-1}$] |
|---|---|
| United States (global default) | 2.9 [a] |
| Australia | 3.6 [b] |

[a] Nowak and Crane 2002; average of 10 US cities.
[b] Brack 2002; modelling analysis in Canberra.

**TABLE 8.2**
**TIER 2B DEFAULT AVERAGE ANNUAL CARBON ACCUMULATION PER TREE IN URBAN TREES BY SPECIES CLASSES**

| Broad species class | Default annual carbon accumulation per tree (tonnes C $yr^{-1}$) |
|---|---|
| Aspen | 0.0096 |
| Soft maple | 0.0118 |
| Mixed hardwood | 0.0100 |
| Hardwood maple | 0.0142 |
| Juniper | 0.0033 |
| Cedar/larch | 0.0072 |
| Douglas fir | 0.0122 |
| True fir/Hemlock | 0.0104 |
| Pine | 0.0087 |
| Spruce | 0.0092 |

Source: D. Nowak (2002; personal communication)

### 8.2.1.3 CHOICE OF ACTIVITY DATA

**Tier 1**

No activity data are needed.

**Tier 2**

The activity data needed to implement a Tier 2 method are either $AT_{ij}$, area of crown cover for each class within a perennial type (Equation 8.2), or $NT_{ij}$, number of individual plants in each class within a perennial type (Equation 8.3). Crown cover is defined as the percent of ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage. For Tier 2a, crown cover area data ($AT_{ij}$) can be obtained from aerial photographs of urban areas, provided expertise in photo interpretation, image sampling and area measurement (Nowak *et al*., 1996) are available. Values in percent crown cover should be converted to total crown cover area for use in Equation 8.2 by multiplying the percent crown cover by the total area of the plants (trees or shrubs) within the outermost perimeter.

If data are not available to determine percent crown cover, then default activity data can be used. This approach takes advantage of the fact that settlements found in different biomes, as defined by different potential natural vegetation or PNV (Kuchler, 1969), have been found to have similar values for percent tree cover, total greenspace, and canopy greenspace (Nowak *et al*., 1996) (Table 8.3). Settlements found in regions where the PNV is forest, for example, have substantially higher percent tree cover values than do settlements found in regions where the PNV is desert (Table 8.3). In Table 8.3, percent total greenspace is the proportion of land area covered by vegetation or soil (i.e., not impervious surfaces or water), and canopy greenspace is the proportion of that greenspace filled with tree canopies (calculated as percent canopy cover/ percent total greenspace). The default data on percent tree crown cover should be multiplied by the settlement area and used with the default growth rates in Table 8.1, in a simplified version of Equation 8.2, to estimate the annual carbon accumulation in the tree perennial type. Data on percent total greenspace and percent canopy greenspace in Table 8.3 are not needed for a Tier 2 approach to estimate biomass carbon stocks, but may be useful for cross-checking.

For Tier 2b, records of plant populations, disaggregated into species or broad species classes, may be obtained from municipal agencies caring for urban vegetation, or from sampling methods.

**Tier 3**

Under Tier 3, the type of activity data to be collected depends on the methodological approaches used. If the stock-difference method is used, then it is necessary to disaggregate and estimate area under different types of vegetation types (parks, rural or urban settlements, avenues, playgrounds, etc) using remote sensing techniques in different climate or economic development indicators. The higher the tier to be used, the more disaggregated will be the activity data, and the more precise the estimation methods. The area sampling methods described in Chapter 3, Annex 3A.3 can be used for this.

**TABLE 8.3**
**DEFAULT ACTIVITY DATA BY POTENTIAL NATURAL VEGETATION (PNV) TYPE (KUCHLER, 1969) FOR PERCENT TREE COVER**

| Potential Natural Vegetation (PNV) | Percent tree cover (± S.E.) | Percent total greenspace (± S.E.) | Percent canopy greenspace (± S.E.) |
|---|---|---|---|
| Forest | 31.1 (± 2.6) | 58.4 (± 2.9) | 50.9 (± 3.3) |
| Grassland | 18.9 (± 1.5) | 54.8 (± 2.1) | 32.9 (± 2.3) |
| Desert | 9.9 (± 2.4) | 64.8 (± 4.2) | 16.9 (± 4.6) |
| Source: Nowak *et al*. (1996) | | | |

## STEP-BY-STEP SUMMARY OF METHOD FOR ESTIMATING CHANGES IN BIOMASS STOCKS

### Tier 1

The Tier 1 methodology assumes no change in biomass carbon stocks in *Settlements Remaining Settlements*.

### Tier 2

*Method A: Crown cover area method*

**Step 1:** Define the total crown cover area in each of the woody perennial types in the settlement. If data are not available for all types, the method may be applied for trees only, setting the area in other perennial types to zero. Default activity data for tree cover can be applied using Table 8.3. To estimate total tree crown cover for a settlement falling in a region where the PNV is grassland, for example, multiply the total land area in the settlement by the 18.9%, which is the average percent tree cover for settlements found in areas where the PNV is grassland, from Table 8.3. The total crown cover area of all vegetation (including trees) is calculated as (total greenspace area = percent greenspace x settlement area) and the aggregated crown cover of the other perennial vegetation types is the difference between the total greenspace area and the tree crown cover area.

**Step 2:** Calculate $\Delta C_G$ for each of the perennial types, using Equation 8.2. The tree crown cover area value obtained in Step 1 should be used for the tree perennial type. Countries may apply a default value of CRW for trees from Table 8.1; should develop and apply their own values for $CRW_{ij}$. Default values are available only for CRW for the tree component of vegetation. If CRW values for other perennial types do not exist and cannot be developed, or if activity data for these types do not exist these parameters may be set to zero, and the tree component of biomass growth only be estimated.

**Step 3:** Calculate $\Delta C_L$ for plant components, to be used in Equation 2.7 in Chapter 2. For the tree component of vegetation, it is *good practice* to set this value equal to zero where the average age of the tree population is less than or equal to the active growing period (AGP; see Section 8.2.1.2). If the average age of trees is greater than the AGP, then either assume $\Delta C_G = \Delta C_L$ or use situation-specific data. In the absence of data to the contrary, assume that $\Delta C_G = \Delta C_L$ for shrubs and herbaceous plants.

**Step 4:** Use the values obtained for $\Delta C_G$ and $\Delta C_L$ in Equation 2.7 in Chapter 2 to quantify the total change in biomass carbon in *Settlements Remaining Settlements*.

*Method B: Individual plant growth method*

**Step 1:** Estimate the number of plants in *Settlements Remaining Settlements* for each perennial type (e.g., trees, shrubs, and herbaceous plants). If data are not available for all of the perennial types, a minimum approach is to use data for trees only, setting the number of plants in other perennial types to zero. There are no default activity data for this method.

**Step 2:** Using Equation 8.3, multiply each estimate by the appropriate rate of carbon increment per plant ($C_{ij}$,) to obtain the amount of carbon sequestered annually. Default $C_{ij}$ values for trees can be found in Table 8.2; there are no default values for shrubs or herbaceous species. Countries may choose to apply their own values if appropriate, or set the missing values to zero and produce estimates for trees only.

**Step 3:** As in Equation 8.2, sum the amount of carbon sequestered, $\Delta C_G$, by each perennial type over all classes present in *Settlements Remaining Settlements*.

**Step 4:** Use the estimate of $\Delta C_G$ in Equation 2.7 in Chapter 2 to estimate the annual change in carbon stock in biomass. For trees, set $\Delta C_L = 0$ if the average age of the tree population is less than or equal to the active growing period (AGP); if average age of trees is greater than the AGP (Section 8.2.1.2), then either assume $\Delta C_G = \Delta C_L$ or use situation-specific data.

**Tier 3**

A Tier 3 approach requires more detailed information than the Tier 2 approach, such as:

- accounting for different land uses within settlements (residential, recreational, industrial, etc.);
- detailed estimates and models for growth and longevity of the most important plant species;
- fate of pruned and dead wood and other biomass transferred to the DOM pool; and
- other items as appropriate for national circumstances.

### 8.2.1.4 UNCERTAINTY ASSESSMENT

**Tier 1**

Assessment of uncertainty is not required, because the change in living biomass is set to zero.

**Tier 2 and Tier 3**

The overall uncertainty of any estimate of the change in the carbon stock of living biomass will be a combination of the individual uncertainties of its component terms. These will be influenced by the heterogeneity between and within land-use urban types, and also by the intensity and frequency of the stewardship of plants in both public and private spaces. The uncertainty is likely to be high since there is limited experience in measuring carbon stock change in urban and rural settlements. The few studies done on the $CO_2$ sink capacity of cities differ in methodology and scope, but the overall relative uncertainty of the estimate of changes in carbon stocks is unlikely to be less than 30-50% about the mean.

## 8.2.2 Dead organic matter

Most of the changes in carbon stocks associated with dead organic matter (DOM) will be associated with changes in tree cover in settlements. Methods are provided for two types of DOM pools: 1) dead wood and 2) litter. Chapter 1of this volume provides detailed definitions of these pools.

Dead wood is a diverse pool with many practical problems for measuring in the field and associated uncertainties about rates of transfer to litter, soil, or emissions to the atmosphere. Amounts of dead wood depend on the time of last disturbance, the amount of input (mortality) at the time of the disturbance, natural mortality rates, decay rates, and management.

Litter accumulation is a function of the annual amount of litterfall, which includes all leaves, twigs and small branches, fruits, flowers, and bark, minus the annual rate of decomposition. The litter mass is influenced by the time since the last disturbance, and the type of disturbance. Management such as wood and grass collection, burning, and grazing dramatically alter litter properties, but there are few studies clearly documenting the effects.

In herbaceous perennial turfgrass communities, thatch accumulates in a thin layer at the soil surface. The depth of this layer depends on the balance between accumulation (grass production) and decomposition, which varies substantially with climate and management regime. While the function of this layer has been recognized (Raturi *et al*., 2004), there are so far no published data on the overall impact of carbon accumulation in this DOM pool on landscape-level. As a result, these *Guidelines* acknowledge the potential importance of thatch in the DOM in settlements but assume that inputs equal outputs so that the net change in carbon stock is zero.

No studies have yet been published on the accumulation rate of dead wood in settlements, though some studies have described the production of leaf litter in settlements (cf. Jo and McPherson, 1995). In the only measured data on this component of carbon flux, Kaye *et al*. (2005) found that leaf and shrub litter in residential lawns in Colorado (USA) totalled 49 g C $m^{-2}$ $yr^{-1}$, or roughly 13% of total above-ground productivity (383 g C $m^{-2}$ $yr^{-1}$). Since the rate of soil respiration in settlements is typically quite high compared to native landscapes (Koerner and Klopatek, 2002; Kaye *et al*., 2005), it is likely that fine litterfall decays quickly. The conservative approach, therefore, is to set the accumulation rate of the litter component of DOM to zero.

### 8.2.2.1 CHOICE OF METHOD

Estimation of changes in carbon stocks in DOM requires an estimate of changes in stocks of dead wood and changes in litter stocks (refer to Equation 2.17 of Chapter 2). Each of the DOM pools is treated separately, but the method for determining changes in each pool is the same. The decision tree in Chapter 2, Figure 2.3 helps select the appropriate tier.

**Tier 1**

Tier 1 assumes that the dead wood and litter stocks are at equilibrium, and so there is no need to estimate the carbon stock changes for these pools. Countries experiencing significant changes in tree cover in settlements are encouraged to develop national data to quantify this change and report it under Tier 2 or 3 methodologies.

**Tiers 2 and 3**

Tiers 2 and 3 allow for calculation of changes in dead wood and litter carbon due to changes in tree cover. Two methods are suggested for estimating associated carbon stock changes.

*Method 1* (Also called the **Gain-Loss Method,** Equation 2.18 in Chapter 2): This involves estimating the area of settlement categories and the average annual transfer into and out of dead wood and litter stocks. It requires an estimate of area under *Settlements Remaining Settlements* according to different climate or ecological zones or settlement types, disturbance regime, management regime, or other factors significantly affecting dead wood and litter carbon pools. It also requires the quantity of biomass transferred into dead wood and litter stocks as well as the quantity of biomass transferred out of the dead wood and litter stocks on per hectare basis according to different settlement types.

*Method 2* (Also called the **Stock-Difference Method,** Equation 2.19 in Chapter 2): This method involves estimating the area of settlements and the dead wood and litter stocks at two periods of time, $t_1$ and $t_2$. The dead wood and litter stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. The Stock-Difference Method is feasible for countries, which have periodic inventories in settlements. This method is more suitable for countries adopting Tier 3 methods. Tier 3 methods are used where countries have country-specific emission factors, and substantial national data. Country-defined methodology may be based on detailed inventories of permanent sample plots for their settlements and/or models.

### 8.2.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

**Carbon fraction:** The carbon fraction of dead wood and litter is variable, particularly for litter, and depends on the stage of decomposition. A value of 0.50 tonne C (tonne d.m.)$^{-1}$ can be used as a default in both cases.

**Tier 1**

Emission factors are unnecessary.

**Tier 2**

It is *good practice* to use country-level data on DOM for different settlement categories, in combination with default values, if country or regional values are not available for some settlement categories. Country-specific values for the transfer of carbon from live trees and grasses that are harvested to harvest residues and decomposition (in the case of the Gain-Loss Method), or the net change in DOM pools (in the case of the Stock-Difference Method), can be derived taking into account domestic expansion factors, settlement types, the rate of biomass utilization, mortality, management and harvesting practices, and the amount of damaged vegetation during management and harvesting operations.

**Tier 3**

Countries should develop their own methodologies and parameters for estimating changes in DOM. These methodologies may be derived from Methods 1 or 2 specified above, or may be based on other modelling or sampling approaches (see sampling methods set out in Chapter 3, Annex 3A.3).

### 8.2.2.3 CHOICE OF ACTIVITY DATA

Activity data consist of areas of *Settlements Remaining Settlements* summarised by major settlement types. Total settlement areas should be consistent with those reported under other sections of this chapter, notably under the biomass section of *Settlements Remaining Settlements*. The assessment of changes in DOM will be greatly facilitated if this information can be used in conjunction with national soils and climate data, vegetation inventories, and other geophysical data.

**Step-by-step summary of method for estimating changes in DOM carbon stocks**

**Tier 1**

Tier 1 assumes DOM inputs and outputs are equal so there are no net annual changes in dead wood or litter carbon stocks and no further assessment is needed.

**Tier 2 or Tier 3 (Method 1, Gain-Loss Method)**

Each of the DOM pools (dead wood and litter) is to be treated separately, but the method for each pool is the same.

**Step 1:** Determine the categories to be used in this assessment and the representative area. The category consists of definitions of the type of settlements. Area data should be obtained using the methods described in Chapter 3.

**Step 2:** Identify values from inventories or scientific studies for the average inputs and outputs of dead wood or litter for each category. No default factors exist for inputs and outputs from these pools, so countries should use locally available data. Calculate the net change in the DOM pools by subtracting the outputs from the inputs. Negative values indicate a net decrease in the stock (Equation 2.18).

**Step 3:** Determine the net change in DOM carbon stocks for each category. Multiply the change in DOM stocks by the carbon fraction of the dead wood or litter to determine the net change in dead wood and litter carbon stocks.

**Step 4:** Determine the total change in the DOM carbon pools for each category by multiplying the representative area of each category by the net change in DOM carbon stocks for that category.

**Step 5:** Determine the total change in carbon stocks in DOM by taking the sum of the total changes in DOM across all categories.

**Tier 2 or Tier 3 (Method 2, Stock-Difference Method)**

Each of the DOM pools is to be treated separately, but the method for each pool is the same.

**Step 1:** Determine the settlement categories and area as described in Step 1 above.

**Step 2:** From the inventory data, identify the inventory time interval, the average stock of DOM at the initial inventory ($t_1$), and the average stock of DOM at the final inventory ($t_2$). Use these figures to calculate the net annual change in DOM stocks by subtracting the DOM stock at $t_1$ from the DOM stock at $t_2$ and dividing this difference by the time interval. A negative value indicates a decrease in the DOM stock (Equation 2.19).

**Step 3:** Determine the net change in DOM carbon stocks for each category. Determine the net change in DOM carbon stocks by multiplying the net change in DOM stocks for each category by the carbon fraction of the DOM.

**Step 4:** Determine the total change in the DOM carbon pool for each activity category by multiplying the representative area of each activity category by the net change in DOM carbon stocks for that category.

**Step 5:** Determine the total change in carbon stocks in DOM by taking the sum of the total changes in DOM across all activity categories.

### 8.2.2.4 UNCERTAINTY ASSESSMENT

There is no need to estimate uncertainty under Tier 1, since DOM pools are assumed to be stable. For Tiers 2 and 3 estimates, sources of uncertainty include the degree of accuracy in land area estimates, carbon increment and loss, carbon stocks, and expansion factor terms. Area data and estimates of uncertainty should be obtained using the methods in Chapter 3 which provides default uncertainties associated with the different approaches. Uncertainties associated with carbon stocks and other parameter values are likely to be at least a factor of three unless country-specific data are available from well designed surveys.

## 8.2.3 Soil carbon

Soils in settlements may be sources or sinks of $CO_2$ depending on previous land use, soil burial or collection during development, and current management, particularly with respect to nutrient and water applications in addition to the type and amount of vegetation cover interspersed among roads, buildings and associated infrastructure (Goldman *et al*., 1995; Pouyat *et al*., 2002; Jo, 2002; Qian and Follett, 2002; Kaye *et al*., 2004). Only a few studies have been conducted at the time of writing that evaluate the effect of settlement management on soil C, and most of the focus has been on North America (e.g., Pouyat *et al*., 2002), making it difficult to generalize. For example, there are likely to be large differences that have not been well studied between settlements in developed countries and developing countries.

Estimating the impact of settlement management on soil C storage will be particularly important in countries with a large portion of land in cities and towns, or high rates of settlement expansion. For mineral soils, the impact of settlement land use and management on soil C stocks can be estimated based on differences in storage among settlement management classes relative to a reference condition, such as other managed land uses, or native lands. Settlement management classes could include turf grass (e.g., lawns and golf courses), urban woodlands, gardens, refuse areas (e.g., garbage dumps), barren areas (exposed soil), and infrastructure (e.g., roadways, houses, and buildings). Although organic soils are less commonly used for settlement development, C is emitted from these soils if they are drained due to enhanced decomposition, similar to the effect of drainage for agricultural purposes (Armentano and Menges, 1986).

*General information and guidelines for estimating changes in soil C stocks are found in Chapter 2, Section 2.3.3, and should be reviewed before proceeding with specific guidelines dealing with settlements.* The total change in soil C stocks for settlements is computed using Equation 2.24 in Chapter 2, which combines the change in soil organic C stocks for mineral soils and organic soils; and stock changes for soil inorganic C pools (Tier 3 only). The next section provides specific guidance on estimating the soil organic C stock change in settlements. For general discussion on soil inorganic C, no additional information is provided in the settlements discussion below.

To account for changes in soil C stocks associated with *Settlements Remaining Settlements*, countries need to have estimates of the relevant settlement area, stratified by climate region and soil type. More detailed inventory estimations can be made through ground-based surveys and/or periodic analyses of remote sensing imagery to determine settlement management classes (e.g., turf grass, urban woodlands, gardens, refuse areas, barren areas and infrastructure).

Inventories can be developed using Tier 1, 2 or 3 approaches, with Tier 3 requiring more detail and resources. It is also possible that countries will use different tiers to prepare estimates for the separate components in this source category, which includes mineral soils and organic soils in addition to soil inorganic C pools, if using a Tier 3 approach. Figures 2.4 and 2.5 in Chapter 2 are decision trees that provide guidance for identification of appropriate tier to estimate changes in carbon stocks in mineral soils and organic soils, respectively.

## 8.2.3.1 CHOICE OF METHOD

### Mineral soils

#### Tier 1

It is assumed in the Tier 1 method that inputs equal outputs so that settlement soil C stocks do not change in *Settlements Remaining Settlements*.

#### Tier 2

The Tier 2 approach for mineral soils uses Equation 2.25 in Chapter 2; involves country- or region-specific reference C stocks and/or stock change factors and possibly suitably disaggregated land-use activity and environmental data.

#### Tier 3

Tier 3 is an advanced method for estimating soil C stocks associated with settlement cover classes, such as a dynamic model or measurement/monitoring network. Few if any models or measurement systems have been developed for estimating soil C stocks in settlements that would be considered a Tier 3 method. This should be considered if settlement soil C is considered a key source category. Additional guidance on Tier 3 approaches is given in Chapter 2, Section 2.3.3

### Organic soils

#### Tiers 1 and 2

Settlements are unlikely to be built on deep organic soils, but if needed, emissions can be computed using Equation 2.26 in Chapter 2. A Tier 2 approach will incorporate country-specific information to estimate emission factors, in addition to a settlement cover classification. However, it is also optional in the Tier 2 approach to use a more detailed classification of climate and soils than the default categories.

#### Tier 3

Tier 3 approaches for organic soils will include more detailed management systems integrating dynamic models and/or measurement networks. Additional guidance on Tier 3 approaches is given in Chapter 2, Section 2.3.3.

## 8.2.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTORS

### Mineral soils

#### Tier 1

It is assumed in the Tier 1 method that inputs equal outputs so that settlement soil C stocks do not change in *Settlements Remaining Settlements*.

#### Tier 2

Since defaults are unavailable, Tier 2 requires estimation of country-specific stock change factors. Equation 2.25 in Chapter 2 uses three levels of stock change factor depending on the land use, the management within the land use, and the level of inputs The inventory compiler should define management classes relevant to settlements (such as turf grass); derive stock change factors for land use ($F_{LU}$) based on the C storage for each class relative to the reference condition which is likely to be native lands. Management factors ($F_{MG}$) give flexibility to specify the way land use is managed (such as for sports fields or ornamental use) and input factors ($F_I$) can be used to represent the influence of management on C of input such as watering or fertilization practices.

**Tier 3**

Tier 3 requires some combination of detailed process models and data gathering, with a sampling strategy and periodic re-sampling, to capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

### Organic soils

**Tier 1**

If soils are drained and the peat is not removed, the emissions can be computed using emission factors for cultivated organic soils, due to deep drainage in settlements similar to croplands. If the peat is removed the carbon should be assumed to be released in the year of removal (see Chapter 5, Cropland).

**Tier 2**

Emission factors are derived from country-specific experimental data in a Tier 2 approach. It is *good practice* for emission factors to be derived for specific settlement management classes and/or a finer classification of climate regions, assuming the new categories capture significant differences in C loss rates. Additional guidance is given in Chapter 2, Section 2.3.3.1.

**Tier 3**

The advice is the same as that given above for mineral soils.

## 8.2.3.3 CHOICE OF ACTIVITY DATA

### Mineral soils

**Tier 1**

It is assumed in the Tier 1 method that inputs equal outputs so that settlement soil C stocks do not change in *Settlements Remaining Settlements*.

**Tier 2**

For the Tier 2 level, activity data consist of areas for settlements subdivided by climate, soil type, and /or management classes, as needed, to correspond with the stock change factors described above. Municipality records may be useful for determining the proportion of various management classes (e.g., shopping areas, subdivisions, businesses, parks, schools, etc.), augmented with knowledge of country experts about the approximate distribution of settlement classes (i.e., turf grass, urban woodlands, gardens, refuse areas, barren areas and infrastructure). Tier 2 approaches may involve a finer stratification of environmental data, including climate regions and soil types, provided the corresponding stock change factors have been developed.

**Tier 3**

The activity data for application of dynamic models and/or a direct measurement-based inventory will characterise climate, soil, topographic and management regime, depending on the model or sampling design.

### Organic soils

**Tier 1**

The total area of cultivated organic soils in settlements, stratified by climate region to correspond to Table 5.6 in Chapter 5 or Table 6.3 in Chapter 6, is needed. A default can be obtained by multiplying total urban area, as a function of climate region, by the area proportion of greenspace from Table 8.3 above.

**Tier 2**

Tier 2 approaches for organic soils will involve more detailed specification of management classes, and possibly finer division of those classes by drainage or climate regions. Stratification should be based on empirical data demonstrating significant differences in C loss rates for the proposed classes.

**Tier 3**

The advice is the same as that given above for mineral soils.

### 8.2.3.4 UNCERTAINTY ASSESSMENT

Uncertainties in soil C inventories are related at Tiers 1 and 2 to representation of 1) land-use and management activities; 2) mineral soil reference C stocks; and 3) stock change and emission factors. Tier 3 uncertainties depend on model structure and parameters, or measurement error/sampling strategy. Uncertainty is generally reduced by more sampling and use of a higher Tier estimates incorporating country-specific information.

Uncertainties in reference C stocks and emission factors are indicated in Table 2.3 in Chapter 2; Tables 5.5 and 5.6 in Chapter 5; and Tables 6.2 and 6.3 in Chapter 6. Uncertainties in land-use and management data will need to be assessed by the inventory compiler, and combined with uncertainties for the default factors and reference C stocks using an appropriate method, such as simple error propagation equations. If using aggregate land-use area statistics for activity data (e.g., FAO data), the inventory compiler may have to apply a default level of uncertainty for the land area estimates (±50%). However, it is *good practice* for the inventory compiler to derive uncertainties from country-specific activity data instead of using a default level.

Default reference C stocks for mineral soils and emission factors for organic soils can have high uncertainties, when applied to specific countries. Defaults represent globally averaged values of land-use and management impacts or reference C stocks that may vary from region-specific values (Powers *et al*., 2004; Ogle *et al*., 2006). Bias can be reduced by deriving country-specific factors using Tier 2 method or by developing a Tier 3 country-specific estimation system. The underlying basis for higher Tier approaches will be research in the country or neighbouring regions that address the effect of land use and management on soil C. It is *good practice* to minimize bias by accounting for significant within-country differences in land-use and management impacts, such as variation among climate regions and/or soil types, even at the expense of reduced precision in the factor estimates (Ogle *et al*., 2006). Bias is more problematic for reporting stock changes because it is not necessarily captured in the uncertainty range (i.e., the true stock change may be outside of the reported uncertainty range if there is significant bias in the factors).

Precision in land-use activity statistics may be improved through a better national system, such as developing or extending a ground-based survey with additional sample locations and/or incorporating remote sensing to provide additional coverage. It is *good practice* to design a classification that captures the majority of land-use and management activity with a sufficient sample size to minimize uncertainty at the national scale.

For Tier 2 methods, country-specific information is incorporated into the inventory analysis for purposes of reducing bias. For example, Ogle *et al*. (2003) utilized country-specific data to construct probability density functions for US specific factors, activity data and reference C stocks for agricultural soils. It is *good practice* to evaluate dependencies among the factors, reference C stocks or land-use and management activity data. In particular, strong dependencies are common in land-use and management activity data because management practices tend to be correlated in time and space.

Tier 3 models are more complex and simple error propagation equations may not be effective at quantifying the associated uncertainty in resulting estimates. Monte Carlo analyses are possible (Smith and Heath, 2001), but can be difficult to implement if the model has many parameters (some models can have several hundred parameters) because joint probability density functions must be constructed quantifying the variance as well as covariance among the parameters. Other methods are also available such as empirically-based approaches (Monte *et al*., 1996), which use measurements from a monitoring network to statistically evaluate the relationship between measured and modelled results (Falloon and Smith, 2003). In contrast to modelling, uncertainties in measurement-based Tier 3 inventories can be determined directly from the sample variance, measurement error and other relevant sources of uncertainty.

# 8.3 LAND CONVERTED TO SETTLEMENTS

Conversion of Forest Land, Cropland, Grassland etc. to Settlements, leads to emissions and removals of greenhouse gases. Methods for estimating change in carbon stocks associated with land-use conversions are explained in Chapters 2, 4, 5 and 6 of this volume. The decision tree (see Figure 1.3 in Chapter 1) and the same basic methods can be applied to estimate change in carbon stocks in Forest Land, Cropland and Grassland converted to Settlements.

Depending on the magnitude of carbon stocks in the previous land-use category, land converted to Settlements may experience a relatively rapid loss of carbon in the first year, followed by a more gradual increase in carbon pools subsequently. Forest Land converted to Settlements, for example, would normally be characterized by this abrupt change followed by a gradual increase in carbon stocks. If carbon stocks in the previous land use were lower than in settlements, this abrupt transition would not take place in the first year. For example, abandoned Cropland converted to Settlements would experience only the gradual carbon stock increase and not the initial abrupt transition.

The methods described can have sometimes been simplified by estimating the effects of conversion in a single year followed by application of the methods described above for *Settlements Remaining Settlements*. However, where this is done, the land area should be kept in the conversion state for the transition period adopted. Otherwise, there are likely to be difficulties with maintaining the consistency of the land-use matrix.

Where Approach 1 is used in its simplest form for land area representation (see Chapter 3) and no supplementary information is available that will allow the previous land uses to be inferred, only the total area of settlements will be known as a function of time and the previous land uses will not be known. Under these circumstances, the biomass stocks before the conversion ($B_{before}$) cannot be estimated and Equation 2.16 cannot be applied. In this case land converted to Settlements will have to be estimated with land remaining Settlements and the emissions or removals from conversion to Settlements as well as other land-use changes will be represented as step changes in the remaining categories rather than properly allocated to the conversions consistent with the land-use change matrix. In effect transitions become step changes across the landscape. This makes it particularly important to achieve coordination among each sector to ensure the total land base is remaining constant over time, given that some land area will be lost and gained within individual sectors during each inventory year due to land-use change.

## 8.3.1 Biomass

### 8.3.1.1 CHOICE OF METHOD

The general approach for calculating the immediate change in live biomass accruing from the conversion to Settlements is represented by Equations 2.15 and 2.16 in Chapter 2. The mean annual biomass increment resulting from the transition is represented by the difference between the biomass in the settlement land-use category immediately after the transition ($B_{After}$) and the biomass in the previous category ($B_{Before}$).

This method follows the approach in the *Guidelines* for other land-use transitions: the annual change in carbon stock in biomass due to land conversion is estimated (using Equation 2.16) by multiplying the area converted annually to settlements by the difference in carbon stocks between biomass in the system prior to conversion ($B_{Before}$) and that in the settlements after conversion ($B_{After}$).

**Tier 1**

For Tier 1, in the initial year following conversion to the settlement land use, the most conservative approach is to set $B_{After}$ to zero, meaning that the process of development of settlements causes carbon stocks to be entirely depleted. To do this it is necessary to add growth during the year of inventory ($\Delta C_G$) and subtract loss ($\Delta C_L$) to obtain the net change in carbon stocks on land converted to Settlements (Equation 2.15).

**Tier 2**

At Tier 2, country-specific carbon stocks can be applied to activity data disaggregated to a level of detail adapted to national circumstances. At the higher tiers, the area of each land-use or land cover type converted to another type in a settlement (examples of land use and land cover types are described in Section 8.2) should be recorded, because that area is associated with the amount of carbon both before and after the conversion. Settlement land-use or land cover types are likely to differ in carbon density.

**Tier 3**

At Tier 3, countries can use the stock difference method (Equation 2.8) or other advanced estimation methods that may involve complex models and highly disaggregated activity data including, if available, more detailed information about $B_{After}$ on a country- or biome-specific basis.

### 8.3.1.2 CHOICE OF EMISSION/REMOVAL FACTORS

**Tier 1**

Tier 1 methods require estimates of the biomass of the land use before conversion and after conversion. It is assumed that all biomass is cleared when preparing a site for settlements, thus, the default for biomass immediately after conversion is 0 tonnes $ha^{-1}$. Table 8.4 provides default values for biomass before conversion ($B_{Before}$).

| **TABLE 8.4**<br>**DEFAULT BIOMASS CARBON STOCKS REMOVED DUE TO LAND CONVERSION TO SETTLEMENTS** | | |
|---|---|---|
| **Land-use category** | **Carbon stock in biomass before conversion ($B_{Before}$) (tonnes C $ha^{-1}$)** | **Error range #** |
| Forest Land | See Chapter 4, Tables 4.7 to 4.12 for carbon stocks in a range of forest types by climate regions. Stocks are in terms of dry matter. Multiply values by a carbon fraction (CF) 0.5 to convert dry matter to carbon. | See Section 4.3 (Land Converted to Forest Land) |
| Grassland | See Table 6.4, Chapter 6 for carbon stocks in a range of grassland types by climate regions. | ± 75% |
| Cropland | For cropland containing annual crops: Use default of 4.7 tonnes of carbon $ha^{-1}$ or 10 tonnes of dry matter $ha^{-1}$ (see Chapter 6, Section 6.3.1.2) | ± 75%. |
| # Represents a nominal estimate of error, equivalent to two times standard deviation, as a percentage of the mean. | | |

**Tiers 2 and 3**

Tier 2 methods replace the default data by country-specific data and Tier 3 involves detailed modelling or measurement data relevant to the conversion processes.

## 8.3.1.3 CHOICE OF ACTIVITY DATA

Activity data for estimating changes in biomass on land areas converted to Settlements can be obtained, consistent with the general principles set out in Chapter 3, through national statistics, from forest services, conservation agencies, municipalities, survey and mapping agencies. Cross-checks should be made to ensure complete and consistent representation of annually converted lands in order to avoid possible omissions or double counting. Data should be disaggregated according to the general climatic categories and settlements types. Tier 3 inventories will require more comprehensive information on the establishment of new settlements, with refined soil classes, climates, and spatial and temporal resolution. All changes having occurred over the number of years selected as the transition period should be included with transitions older than the transition period (default 20 years) reported as a subdivision of *Settlements Remaining Settlements*.

Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* is that the areas of Forest Land conversion can be identified separately. This is because forest will usually have higher carbon density before conversion. This implies that at least partial knowledge of the land-use change matrix, and therefore, where Approaches 1 and 2 from Chapter 3 are used to estimate land area, supplementary surveys may be needed to identify the area of land being converted from Forest Land to Settlements. As pointed out in Chapter 3, where surveys are being set up, it will often be more accurate to seek to establish directly, areas undergoing conversion, than to estimate these from the differences in total land areas under particular uses at different times.

### Step by step method for implementation

**Tier 1**

Use default values for $B_{before}$ from respective land-use category chapter (Forest Land, Grassland, etc) and assume that $B_{After}$ equals zero in Equation 2.16.

**Step 1:** Apply Equation 2.16 to each land-use type converted to settlement lands;

**Step 2:** Add up the biomass changes over all the land-use types; and

**Step 3:** Multiply the result by 44/12 to obtain the amount of $CO_2$ equivalents emitted (the sum obtained in Step 2 will be a negative number) from the land conversion.

**Tier 2**

The typical steps to implement a Tier 2 method are:

**Step 1:** Use the methods described in Chapter 3, including where relevant cadastral and planning records or the analysis of remote sensing images (or both), to estimate the change in area between the present and the last area survey.

**Step 2:** Define — as a first approximation — settlement land-use types on the basis of the proportion of greenspace. For instance, three tentative land-use classes could be: Low (less than 33% greenspace), Medium (from 33 to less than 66% greenspace), and High (more than 66% greenspace). Each one of those classes can be assigned with an average carbon content, obtained from the species surveyed in similarly defined classes for accounting biomass changes in Section 8.2.

**Step 3:** Draw a land-use conversion area matrix for the land-use transitions defined in Step 2.

**Step 4:** Estimate with equations the biomass stocks of the defined land-use types and the converted land-use types (to obtain $B_{Before}$ and $B_{After}$), apply Equation 2.16 to each non-empty cell of the land-use change matrix, add up the changes in carbon stocks, and multiply the sum by 44/12 to obtain the emission/removal of $CO_2$ equivalents.

**Step 5:** Calculate $\Delta C_G$, using either Method A or Method B in Section 8.2.1, *Settlements Remaining Settlements* (the choice of method will depend on the applicability of the emission and removal factors, as well as the availability of activity data). This will be used in Equation 2.15.

**Step 6:** Calculate $\Delta C_L$, using Methods as described in Section 8.2.1.3, *Settlements Remaining Settlements*.

**Step 7:** Calculate the change in carbon stocks in live biomass resulting from the land-use transition to Settlements, accounting for the biomass increment, biomass losses, and biomass change due to land-use conversion as given in Equation 2.15.

### 8.3.1.4 UNCERTAINTY ASSESSMENT

See guidance in Section 8.2.1.4.

## 8.3.2 Dead organic matter

Methods are provided for two types of DOM pools: 1) dead wood and 2) litter. Chapter 1of this report provides definitions of these pools and Section 8.2.2 DOM in the context of settlements.

Some land converted to Settlements will not have an abrupt transition (e.g., Cropland that is abandoned and converted to Settlements). In this case, Phase 1 methods will not be appropriate and there will be a gradual transition in DOM pools to a new equilibrium. When this type of conversion occurs, the whole conversion accounting can be treated with Phase 2 methods.

### 8.3.2.1 CHOICE OF METHOD

Estimation of changes in carbon stocks in DOM requires separate estimates of changes in stocks of dead wood and changes in litter stocks (refer to Equation 2. 17 of Chapter 2). The decision tree in Figure 2.3 in Chapter 2 helps select the appropriate tier to use.

**Tier 1**
Tier 1 default assumes all carbon contained in dead wood and litter is lost during conversion and does not take account of any subsequent accumulation.

**Tier 2**
Tier 2 approaches require greater disaggregation than that used in Tier 1. The immediate and abrupt carbon stock change in dead wood due to conversion of other lands to Settlements under Tiers 2 and 3 will be estimated using Equation 2.23, where $C_o$ is set to zero and $T_{on}$ is set at 1 year. Tier 2 assumes a linear change function, although during the transition period, pools that gain or lose C often have a non-linear loss or accumulation curve that can be represented at Tier 3 through successive transition matrices.

For the calculation of changes in dead wood and litter carbon during the transition phase, two methods are suggested:

*Method 1* (Also called the **Gain-Loss Method,** Equation 2.18 in Chapter 2): This method involves estimating the area of each type of land conversion and the average annual transfer into and out of dead wood and litter stocks. This requires an estimate of area under land converted to Settlements according to different climate or ecological zones or settlement types, disturbance regime, management regime, or other factors significantly affecting dead wood and litter carbon pools and the quantity of biomass transferred into dead wood and litter stocks as well as the quantity of biomass transferred out of the dead wood and litter stocks on per hectare basis according to different settlement types.

*Method 2* (Also called the **Stock-Difference Method,** Equation 2.19 in Chapter 2): This method involves estimating the area of land converted to Settlements and the dead wood and litter stocks at two periods of time, $t_1$ and $t_2$. The dead wood and litter stock changes for the inventory year are obtained by dividing the stock changes by the period (years) between two measurements. The stock-difference method is feasible for countries, which have periodic inventories.

**Tier 3**

For Tier 3, countries should develop their own methodologies and parameters for estimating changes in DOM. These methodologies may be derived from Methods 1 or 2 specified above, or may be based on other approaches. The method used needs to be clearly documented. A Tier 3 approach should use or be consistent with the true shapes of the loss or accumulation curves. These curves should be applied to each cohort that is under transition during the reporting year to estimate the annual change in the dead wood and litter carbon pools.

## 8.3.2.2 CHOICE OF EMISSION/REMOVAL FACTORS

**Carbon fraction:** The carbon fraction of dead wood and litter is variable and depends on the stage of decomposition. Wood is much less variable than litter and a value of 0.50 tonne C (tonne d.m.)$^{-1}$ can be used for the carbon fraction. Litter values in settlements range from 0.30 to 0.50. When country- or ecosystem-specific data are not available we suggest a carbon fraction value of 0.40 for litter.

**Tier 1**

Dead wood and litter carbon stocks in lands converted to Settlements are assumed all lost during the conversion and there is assumed to be no subsequent accumulation of new DOM in the settlements after conversion. Default values for forest litter prior to conversion are provided in Table 2.2 in Chapter 2 but there are no default values available for dead wood or litter in most systems. Countries should seek estimates and use local data from forestry and agricultural research institutes to provide best estimates of the dead wood and litter in the initial system prior to conversion, or use the defaults in Table 2.2 in the absence of other information. Carbon stocks in litter and dead wood pools in all non-forest land categories are assumed to be zero. Countries experiencing significant conversions of other ecosystems to settlements are encouraged to develop domestic data to quantify this impact and report it under Tier 2 or 3 methodologies.

**Tier 2**

It is *good practice* to use country-level data on dead wood and litter for different settlements categories, in combination with default values if country or regional values are not available for some conversion categories. Country-specific values for the transfer of carbon from live trees and grasses that are harvested to harvest residues and decomposition rates, in the case of the Gain-Loss Method, or the net change in DOM pools in the case of the Stock-Difference Method, can be derived from domestic expansion factors, taking into account the settlements type, the rate of biomass utilization, harvesting practices and the amount of damaged vegetation during harvesting operations. Country-specific values for disturbance regimes should be derived from scientific studies.

**Tier 3**

National level disaggregated DOM carbon estimates should be determined as part of a national inventory, national level models, or from a dedicated greenhouse gas inventory programme, with periodic sampling according to the principles set out in Chapter 3, Annex 3A.3. Inventory data can be coupled with modelling studies to capture the dynamics of all settlements carbon pools.

Tier 3 methods provide estimates of greater certainty than lower tiers and feature a greater link between individual carbon pools. Some countries have developed disturbance matrices that provide a carbon reallocation pattern among different pools for each type of disturbance. Other important parameters in a modelled DOM carbon budget are decay rates, which may vary with the type of wood and microclimatic conditions, and site preparation procedures (e.g., controlled broadcast burning, or burning of piles).

## 8.3.2.3 CHOICE OF ACTIVITY DATA

The activity data should be the same as that used for biomass and described in Section 8.3.1.3

### Step-by-step summary of method for estimating changes in DOM stocks

**Tier 1**

**Step 1:** Determine the categories of land conversion to be used in this assessment and the representative area of conversion by year. Area data should be obtained using the methods described in Chapter 3. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines*, when using Tier 1, is that the areas of forest conversion are identified separately.

**Step 2:** For each activity category, determine the dead wood and litter stocks (separately) per hectare prior to conversion (see Table 2.2 in Chapter 2 for default values).

**Step 3:** For each activity category, determine the stocks in the dead wood and litter (separately) per hectare for the particular type of settlement. For Tier 1, dead wood and litter stocks following conversion are assumed to be equal to zero.

**Step 4:** Calculate the net change of dead wood and litter stocks per hectare for each type of conversion by subtracting the initial stocks from the final stocks. A negative value indicates a loss in the stock (Equation 2.23).

**Step 5:** Convert the net change in the individual stock to units of tonnes C $ha^{-1}$ by multiplying the net stock change by the carbon fraction of that stock (0.40 tonne C $(tonne\ d.m.)^{-1}$ for litter and 0.50 tonne C $(tonne\ d.m.)^{-1}$ for dead wood).

**Step 6:** Multiply the net change in each C stock by the area converted during the reporting year.

**Tiers 2 and 3**

**Step 1:** Determine the categories of land conversion to be used in this assessment and the representative area of conversion by year. When calculating for lands in the transition phase, representative areas for each category at different stages of conversion are required. Higher tiers require greater detail but the minimum requirement for inventories to be consistent with the *IPCC Guidelines* is that the areas of forest conversion are identified separately.

**Step 2: Abrupt changes**

- Determine the activity categories to be used in this assessment and the representative areas. The activity category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and settlements management, for example: 'conversion of logged tropical seasonal forest to cattle pasture using exotic grasses'. Area data should be obtained using the methods described in Chapter 3.
- For each activity category, determine the dead wood and litter stocks (separately) per hectare prior to conversion.
- For each activity category, determine the stocks in the dead wood and litter (separately) per hectare following one year of conversion to Settlements.
- Calculate the net change of dead wood and litter stocks per hectare for each type of conversion by subtracting the initial stocks from the final stocks. A negative value indicates a loss in the stock.
- Convert the net change in the individual stock to units of tonnes C $ha^{-1}$ by multiplying the net stock change by the carbon fraction of that stock (0.40 tonne C $(tonne\ d.m.)^{-1}$ for litter and 0.50 tonne C $(tonne\ d.m.)^{-1}$ for dead wood).
- Multiply the net change in each C stock by the area converted during the reporting year.

**Step 3: Transitional changes**

- Determine the categories and cohorts to be used in this assessment and the representative areas. The category consists of definitions of the type of conversion and, if applicable, the nature of management of the previous land cover and settlements type. Area data should be obtained using the methods described in Chapter 3.
- Determine the annual change rate for dead wood and litter stocks (separately) by activity type using either **the Gain-Loss Method or the Stock-Difference Method (see below)** for each cohort of lands that are currently in the transition phase between conversion and a new steady-state.
- Determine the dead wood and litter stocks in the cohort during the previous year (usually taken from the previous inventory).
- Calculate the change in dead wood and litter stocks for each cohort by adding the net change rate to the previous year's stocks.
- Convert the net change in the individual stock to units of tonnes C $ha^{-1}$ by multiplying the net stock change by the carbon fraction of that stock (0.40 tonne C $(tonne\ d.m.)^{-1}$ for litter and 0.50 tonne C $(tonne\ d.m.)^{-1}$ for dead wood).
- Multiply the net change in each C stock by the area in each cohort for the reporting year.

**Gain-Loss Method**

- Determine the average annual inputs of dead wood and litter (separately).
- Determine the average annual losses of dead wood and litter (separately).
- Determine the net change rate in dead wood and litter by subtracting the outputs from the inputs.

**Stock-Difference Method**

- Determine the inventory time interval, the average stocks of dead wood and litter at the initial inventory, and the average stocks of dead wood and litter at the final inventory.
- Use these figures to calculate the net change in dead wood and litter stocks by subtracting the initial stock from the final stock and dividing this difference by the number of years between inventories. A negative value indicates a loss in the stock.
- A Tier 3 approach requires country- or region-specific expansion factors. There are no default expansion factors for Tier 2, and the best available local data should be used (and documented).

#### 8.3.2.4 UNCERTAINTY ASSESSMENT

Uncertainty at Tier 1 is the same as the uncertainty in the carbon stock on the area of land subject to annual conversion. DOM changes are subsequently assumed to be zero, and no associated uncertainty is needed at Tier 1 after the initial transition. For Tiers 2 and 3 estimates, sources of uncertainty include the degree of accuracy in land area estimates, carbon increment and loss, carbon stocks, amount of carbon burned, and expansion factor terms. Area data and estimates of uncertainty should be obtained using the methods in Chapter 3 which provide default uncertainties associated with the different approaches. Uncertainties associated with carbon stocks and other parameter values are likely to be at least a factor of three unless country-specific data are available from well designed surveys.

## 8.3.3 Soil carbon

Land conversion to Settlements occurs with development and expansion of cities and towns on former Forest Land, Cropland, Grassland, Wetlands, and Other Land. These conversions change soil C stocks due to mechanical disturbance of the soil; soil burial or collection during development; type and amount of vegetated cover; in addition to the new management regime, particularly with respect to nutrient and water applications.

*General information and guidelines for estimating changes in soil C stocks are found in Chapter 2, Section 2.3.3 (including equations).* The total change in soil C stocks for *Land Converted to Settlements* is computed using Equation 2.24, which combines the change in soil organic C stocks for mineral soils and organic soils; and stock changes associated with soil inorganic C pools (for Tier 3 only).

To account for changes in soil C stocks associated with land converted to Settlements, countries need to have estimates of the areas of land converted to Settlements during the inventory time period, stratified by climate region and soil type. If aggregate land-use data are used and specific conversions among uses are not known, soil organic C (SOC) stock changes can still be computed using the methods provided in *Settlements Remaining Settlements*, but the land-base area will then probably be different for settlements in the current year relative to the initial year in the inventory, and the dynamics of the transition will be less well represented. Chapter 3 (Consistent representation of lands) emphasises the importance of maintaining consistency in total land area.

#### 8.3.3.1 CHOICE OF METHOD

Inventories can be developed using Tier 1, 2 or 3 approaches, with each successive Tier requiring more detail and resources than the previous one. It is also possible that countries may use different tiers to prepare estimates for the separate sub-categories of soil C (i.e., soil organic C stocks changes in mineral soils and organic soils, and stock changes associated with soil inorganic C pools, are estimated at Tier 3). Decision trees are provided for mineral soils (Figure 2.4) and organic soils (Figure 2.5) in Section 2.3.3.1 (Chapter 2) to help selection of the appropriate tiers.

**Mineral soils**

**Tier 1**

Change in soil organic C stocks can be estimated for mineral soils with land-use conversion to Settlements using Equation 2.25 in Chapter 2. For Tier 1, the initial (pre-conversion) soil organic C stock ($SOC_{(0-T)}$) and C stock in the last year of the inventory time period ($SOC_0$) are determined from the common set of reference soil organic

C stocks ($SOC_{REF}$) and default stock change factors ($F_{LU}$, $F_{MG}$, $F_I$). Areas of exposed bedrock in Forest Land or the previous land use are not included in the soil C stock calculation (assume a stock of 0). Annual rates of emissions (source) or removals (sink) are calculated as the difference in stocks (over time) divided by the time dependence (D) of the stock change factors (default is 20 years).

**Tier 2**

The Tier 2 approach for mineral soils also uses Equation 2.25 in Chapter 2, but involves country- or region-specific reference C stocks and/or stock change factors and possibly more disaggregated land-use activity and environmental data. Removal, translocation or burial of soil C during development is a particular issue for settlements. To the extent that soil C is not decomposed during the development phase and resides deeper in the profile, is translocated to another area, or possibly used as a commodity. It is *good practice* for Tier 2 stock change factor to be adjusted to reflect the reduction in loss of C to the atmosphere as $CO_2$.

**Tier 3**

Tier 3 methods will involve more detailed and country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data. It is *good practice* that Tier 3 approaches for estimating soil C change from land-use conversions to Settlements, employ models, data sets and/or monitoring networks that are capable of representing transitions over time from other land uses, including Forest Land, Grassland, Cropland or other lands. Tier 3 methods need to be integrated with estimates of biomass removal and the post-clearance treatment of plant residues (including woody debris and litter), as variation in the removal and treatment of residues (e.g., burning, site preparation) will affect C inputs to soil organic matter formation and C losses through decomposition and combustion. Models should be validated with independent observations from country- or region-specific field locations that are representative of the interactions of climate, soil and management on post-conversion change in soil C stocks.

### Organic soils

**Tiers 1 and 2**

Land converted to Settlements on organic soils within the inventory time period is treated the same as *Settlements Remaining Settlements*. Carbon losses are computed using Equation 2.26 in Chapter 2. Additional guidance on Tiers 1 and 2 approaches are given in Section 8.2.3.1.

**Tier 3**

As with mineral soils, a Tier 3 approach will involve country-specific models and/or measurement-based approaches along with highly disaggregated land-use and management data.

## 8.3.3.2 CHOICE OF STOCK CHANGE AND EMISSION FACTOR

### Mineral soils

**Tier 1**

Default reference C stocks are found in Table 2.3 of Chapter 2, and stock change factors for previous land uses can be found in the relevant Chapters (for Forest Land in Section 4.2.3.2, Cropland in 5.2.3.2, Grassland in 6.2.3.2, and Other Land in 9.3.3.2). Default stock change factors for land use after conversion (Settlements) are not needed for the Tier 1 method for *Settlements Remaining Settlements* because the default assumption is that inputs equal outputs and therefore no net change in soil carbon stocks occur once the settlement is established. Conversions, however, may entail net changes and it is *good practice* to use the following assumptions:

(i) for the proportion of the settlement area that is paved over, assume product of $F_{LU}$, $F_{MG}$ and $F_I$ is 0.8 times the corresponding product for the previous land use (i.e., 20% of the soil carbon relative to the previous land use will be lost as a result of disturbance, removal or relocation);

(ii) for the proportion of the settlement area that is turfgrass, use the appropriate values for improved grassland from Table 6.2, Chapter 6;

(iii) for the proportion of the settlement area that is cultivated soil (e.g., used for horticulture) use the no-till $F_{MG}$ values from Table 5.5 (Chapter 5) with $F_I$ equal to 1; and

(iv) for the proportion of the settlement area that is wooded assume all stock change factors equal 1.

**Tier 2**

Estimation of country-specific stock change factors is probably the most important development associated with the Tier 2 approach. Differences in soil organic C stocks among land uses are computed relative to a reference condition, using land-use factors ($F_{LU}$). Input factor ($F_I$) and management factor ($F_{MG}$) are then used to further refine the C stocks of the settlement management classes. Additional guidance on how to derive these stock change factors is given in *Settlements Remaining Settlements*, Section 8.2.3.2. See the appropriate section for specific information regarding the derivation of stock change factors for other land-use sectors (Forest Land in

Chapter 4, Cropland in Chapter 5, Grassland in Chapter 6, and Other Land in Chapter 9). Reference C stocks can also be derived from country-specific data in a Tier 2 approach and should of course be consistent across the land uses (i.e., Forest Land, Cropland, Grassland, Settlements, Other Land), and therefore coordinated among the various teams conducting soil C inventories for AFOLU.

**Tier 3**

Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

**Organic soils**

**Tiers 1 and 2**

Land converted to Settlements on organic soils within the inventory period is treated the same as *Settlements Remaining Settlements*. Tier 2 emission factors are derived from country- or region-specific data; additional guidance is given in Section 8.2.3.2.

**Tier 3**

Constant emission rate factors *per se* are less likely to be estimated in favor of variable rates that more accurately capture land-use and management effects. See Chapter 2, Section 2.3.3.1 for further discussion.

### 8.3.3.3 CHOICE OF ACTIVITY DATA

**Mineral soils**

**Tiers 1 and 2**

The amount of land converted to Settlements, stratified by climate region and soil type, is needed to estimate the appropriate stocks at the Tier 1 level. This can be based on overlays with suitable climate and soil maps and spatially-explicit data of the location of land conversions. Detailed descriptions of the default climate and soil classification schemes are provided in Chapter 3. In the absence of specific information, default area within the settlements that is paved over should be estimated as the non-greenspace proportion of the total area, using the data in Table 8.3, and the same Table can be used to partition the greenspace area into wooded areas and non-wooded areas. The latter may be assumed all to be turfgrass unless data are available on the area otherwise cultivated.

**Tier 3**

For application of dynamic models and/or a direct measurement-based inventory in Tier 3, similar or more detailed data on the combinations of climate, soil, topographic and management data are needed, but the exact requirements will depend on the model or measurement design.

**Organic soils**

**Tiers 1 and 2**

Land converted to Settlements on organic soils within the inventory time period is treated the same as *Settlements Remaining Settlements*, and guidance on activity data is discussed in Section 8.2.3.3.

**Tier 3**

As with mineral soils, Tier 3 approaches will likely require more detailed data on the combinations of climate, soil, topographic and management data, relative to Tier 1 or 2 methods, but the exact requirements will be dependent on the model or measurement design.

### 8.3.3.4 UNCERTAINTY ASSESSMENT

See guidance in Section 8.2.3.4.

# 8.4 COMPLETENESS, TIME SERIES, QA/QC, AND REPORTING

## 8.4.1 Completeness

It is *good practice* for soil C inventories to track the changes in total area over time, and if using a Tier 2 or 3 approach, the inventory should track areas associated with the major management classes (e.g., turf grass, urban woodlands, gardens, refuse areas, barren areas and infrastructure). The total area covered by the settlement inventory methodology is the sum of land in *Settlements Remaining in Settlements* and *Land Converted to*

*Settlements* during the time period. This inventory methodology may not include some settlement areas where greenhouse gas emissions and removals are believed to be insignificant or constant through time because of little or no change in settlement management or no significant change in management inputs. However, countries are encouraged to track through time the total area of land in settlements within country boundaries, keeping transparent records on which portions are used to estimate carbon dioxide emissions and removals. In this case, it is *good practice* for countries to document and explain the difference in the area that is included in the inventory computations and the total settlement area in the land base.

## 8.4.2 Developing a consistent time series

To maintain a consistent time series, it is *good practice* for countries to apply the same inventory methods over the entire reporting time period, including definitions for land-use and settlement systems, area included in a C inventory, and calculation method. If changes are made, it is *good practice* to keep transparent records of the changes, and then re-calculate the C stock changes over the entire inventory time period. Guidance on re-calculation under these circumstances is given in Volume 1, Chapter 5. Consistent estimation and reporting also requires common definitions of management activities, climate and soil types across the entire time series for the period of the inventory.

## 8.4.3 Inventory Quality Assurance/Quality Control

It is *good practice* to implement quality control checks and external expert review of inventory estimates and data. Specific attention is expected to be paid to country-specific estimates of stock change and emission factors, ensuring that they are based on high quality data and verifiable expert opinion.

Specific QA/QC checks across the settlements methodology include:

*Settlements Remaining Settlements*: It is *good practice* for settlement areas to be consistent for reporting of biomass stock and soil stock changes. Settlements may include areas where soil stock changes are accounted for but biomass changes are assumed to be zero (e.g., where non-woody biomass is largely absent), areas where both biomass and soil stocks are changing (e.g., development of a park), and areas where neither biomass nor soil stocks are changing (e.g., infrastructure and barren areas). To increase transparency and eliminate errors, it is *good practice* to report the total settlement area regardless of whether stocks are changing.

*Land Converted to Settlements*: Aggregate area totals for land converted to Settlements are expected to be the same in the biomass and soils estimations. While biomass and soil pools may be disaggregated to different levels of detail, it is *good practice* to use the same general categories for disaggregating the area data.

For all soil C stock change estimates, it is expected that the total areas will be the same for each climate-soil type combination at the beginning ($year_{(0-T)}$) and the last year ($year_{(0)}$) of the inventory time period, unless it has been demonstrated that some portion of the land base has been incorporated into another land-use sector or gained from another sector. Ultimately, the sum of the entire land base for a country, which includes each sector, must be equal across every year in the inventory time period.

## 8.4.4 Reporting and Documentation

It is *good practice* to maintain and archive all information used to produce national inventory estimates including: (i) data sources, databases, data sources for information used to estimate country-specific factors as well as the procedures used to estimate factors; (ii) activity data and definitions used to categorize or aggregate the activity data; and (iii) climate region classifications and soil types (for Tier 1 and Tier 2) must be clearly documented. For Tier 3 approaches using modelling, it is *good practice* to document the model version and provide a model description, in addition to permanently archiving copies of all model input files, source code and executable programs.

### Reporting tables and worksheets

The categories described in this Chapter can be reported using the reporting tables in Volume 1, Chapter 8. The estimates under the Settlements category can be compared with the reporting categories in the *IPCC Guidelines* as follows:

- Carbon dioxide emissions and removals in woody biomass in *Settlements Remaining Settlements* to IPCC reporting category 5A and *Land Converted to Settlements* in IPCC reporting category 5B; and IPCC reporting categories 4E and 4F for non-$CO_2$ gases;

- Carbon dioxide emissions and removals in soils in *Settlements Remaining Settlements* to IPCC reporting categories 5D and 5E for $CO_2$, and IPCC reporting category 4D for non-$CO_2$ gases; and
- Carbon dioxide emissions and removals resulting from land-use conversions to Settlements to IPCC reporting category 5B for biomass, IPCC reporting categories 5D and 5E for soils; and IPCC reporting categories 4D, 4E, and 4F for non-$CO_2$ gases.

Worksheets are provided in Annex 1 for calculating greenhouse gases emissions and removals (Tier 1 methods) for Settlements.

# 8.5 BASIS FOR FUTURE METHODOLOGICAL DEVELOPMENT

Gaps in this methodology exist because sufficient data are not available to quantify all of the pools and fluxes of greenhouse gases in settlements. Obvious gaps include:

- Methodology for estimating emissions of non-$CO_2$ greenhouse gases ($N_2O$ and $CH_4$);
- Detailed methodology to account for carbon stocks other than live biomass and soils (specifically, dead wood and litter);
- Discussion of carbon stocks and fluxes from turfgrass and turf management;
- Discussion of carbon stocks and fluxes from gardens and other herbaceous plants; and
- A generalized methodology to account for different classes of settled lands, with different amounts of woody and non-woody vegetation and different types of management.

**Non-$CO_2$ greenhouse gases.** While some evidence exists to support the idea that nitrous oxide fluxes may be enhanced in urban areas relative to the native condition (Kaye *et al*., 2004), this result likely depends on the native condition (i.e., the climate and region in which the settlement is located) and the management regime typically applied in that settled area. Additional data are required before conclusions about the impact of settlement on non-$CO_2$ greenhouse gas fluxes can be drawn.

**Dead wood and litter.** Dead wood is a class variously composed of fallen or pruned branches or trees, or dead standing trees not yet replaced with live individuals. This dead wood may be burned or disposed of as solid waste, used for composting, left to decay either in-site or off-site. This material is treated in this methodology as a loss from the live biomass term. Because dead wood is likely to be carried off-site in settlements (rather than left on-site to decay as in forests), a more detailed methodology developed in the future might account for the proportion of dead wood taken to landfills, disposed of in compost piles, burned, or left on-site to decay. The portion taken to landfills or composted might be treated as harvested wood products (HWP) or as waste, both of which are treated in other sections of the *Guidelines*.

**Turfgrass and turf management.** Turfgrass biomass consists of roots, stubble, thatch, and above-ground components. Though estimates of turfgrass productivity have been published (Falk, 1976; Falk, 1980; Qian *et al*., 2003), grass decomposes quickly and there is little information about the overall accumulation of biomass in the longer-lived components of turf biomass. Turfgrass allocation to the above-ground and below-ground components also depends on the management and mowing regime. Because of the lack of generalizable information on this topic, as well as the lack of activity data quantifying the area covered by turfgrass in settlements, there is currently no detailed methodology describing carbon removed by turf systems. A more detailed methodology would require additional information on turf productivity, turfgrass turnover, and allocation to different plant components as it varies with management regime. Of course, the activity data required to implement this methodology would include information on management regimes and the proportion of settlements covered by turfgrass.

**Gardens and other herbaceous plants**. Similar to the situation with turfgrass, information does not exist describing the annual biomass accumulation and allocation of garden plants to different above-ground and below-ground parts. Similarly, information is not available describing the variation in plant productivity with management regime. Activity data required to implement a more detailed methodology would include information on management regimes and the proportion of settlement area covered by this type of vegetation. These are mainly garden plants, so sampling them in private gardens presents the additional problem of their likely disturbance and consequent denial of access to them (cf. Jo and McPherson, 1995).

**Land classes**. A more detailed methodology would benefit from a consistent set of definitions of land classes *within* settlements, that could be applied to any country regardless of its climate, native vegetation, or typical settlement regime. This would make settlements parallel to other land uses – Forest Land, Grassland, Cropland, Wetlands – which are easily defined based on a set of measurable and objective parameters. Some research has been applied in this direction (Theobald, 2004), but current classifications are inconsistent. While the rate of carbon sequestration per unit of tree crown cover is fairly consistent, for example, the overall rate of carbon storage per unit of settlement area depends entirely on the relative amounts of tree and turfgrass cover within that settlement. This land classification would be part of the set of activity data collected by countries, and the detailed methodology could be developed and applied consistently based on those land cover data. This type of land-use classification would also enable countries to account for changes in carbon storage resulting from management changes within areas broadly classified as settlements. For example, when vacant plots are developed, the adventitious vegetation remaining in the non-built areas might be replaced with landscape species differing in ability to store carbon.

# References


Akbari, H. (2002). Shade trees reduce building energy use and $CO_2$ emissions from power plants. *Environmental Pollution* **116**:S119-S124.

Armentano, T.V. and Menges, E.S. (1986). Patterns of change in the carbon balance of organic soil-wetlands of the temperate zone. *Journal of Ecology* **74**:755-774. 1986.

Brack, C.L. (2002). Pollution mitigation and carbon sequestration by an urban forest. *Environmental Pollution* **116**:S195-S200.

Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A. (1997). Root biomass allocation in the world's upland forests. *Oecologia* **111**:1-11.

Crane, P. and Kinzig, A. (2005). Nature in the metropolis. *Science* **308**:1225-1225.

Elvidge, C.D., Milesi, C., Dietz, J.B., Tuttle, B.T., Sutton, P.C., Nemani, R. and Vogelmann, J.E. (2004). U.S. constructed area approaches the size of Ohio. *EOS - Transactions of the American Geophysical Union* **85**:233-234.

Falk, J. (1980). The primary productivity of lawns in a temperate environment. *Journal of Applied Ecology* **17**:689-696.

Falk, J.H. (1976). Energetics of a suburban lawn ecosystem. *Ecology* **57**:141-150.

Gallo, K.P., Elvidge, C.D., Yang, L. and Reed, B.C. (2004). Trends in night-time city lights and vegetation indices associated with urbanization within the conterminous USA. *International Journal Of Remote Sensing* **25**:2003-2007.

Goldman, M.B., Groffman, P.M., Pouyat, R.V., McDonnell, M.J. and Pickett, S.T.A. (1995). $CH_4$ uptake and N availability in forest soils along an urban to rural gradient. *Soil Biology and Biochemistry* **27**:281-286.

Gregg, J.W., Jones, C.G. and Dawson, T.E. (2003). Urbanization effects on tree growth in the vicinity of New York City. *Nature* **424**:183-187.

Idso, C., Idso, S. and Balling, R.J. (1998). The urban $CO_2$ dome of Phoenix, Arizona. *Physical Geography* **19**:95-108.

Idso, C., Idso, S. and Balling, R.J. (2001). An intensive two-week study of an urban $CO_2$ dome. *Atmospheric Environment* **35**:995-1000.

Imhoff, M., Tucker, C., Lawrence, W. and Stutzer, D. (2000). The use of multisource satellite and geospatial data to study the effect of urbanization on primary productivity in the United States. *IEEE Transactions on Geoscience and Remote Sensing* **38**:2549-2556.

IPCC (1997). Revised 1996 IPCC Guidelines for National Greenhouse Inventories. Houghton J.T., Meira Filho L.G., Lim B., Tréanton K., Mamaty I., Bonduki Y., Griggs D.J. Callander B.A. (Eds). Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA, Paris, France.

IPCC (2003). Good Practice Guidance for Land Use, Land-Use Change and Forestry. Penman J., Gytarsky M., Hiraishi T., Krug, T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K., Wagner F. (Eds).Intergovernmental Panel on Climate Change (IPCC), IPCC/IGES, Hayama, Japan.

Jenkins, J., Chojnacky, D., Heath, L. and Birdsey, R. (2004). Comprehensive database of diameter-based biomass regressions for North American tree species. General Technical Report NE-, USDA Forest Service Northeastern Research Station, Newtown Square, PA.

Jo, H. (2002). Impacts of urban greenspace on offsetting carbon emissions for middle Korea. *Journal of Environmental Management* **64**:115-126.

Jo, H. and McPherson, E. (1995). Carbon storage and flux in urban residential greenspace. *Journal of Environmental Management* **45**:109-133.

Kaye, J., Burke, I., Mosier, A. and Guerschman, J. (2004). Methane and nitrous oxide fluxes from urban soils to the atmosphere. *Ecological Applications* **14**:975-981.

Kaye, J.P., McCulley, R.L. and Burke, I.C. (2005). Carbon fluxes, nitrogen cycling, and soil microbial communities in adjacent urban, native and agricultural ecosystems. *Global Change Biology* **11**:575-587.

Koerner, B., and Klopatek, J. (2002). Anthropogenic and natural $CO_2$ emission sources in an arid urban environment. *Environmental Pollution* **116**:S45-S51.

Kuchler, A. (1969). Potential natural vegetation. US Geological Survey Map, Sheet 90, Washington, DC.

Milesi, C., Elvidge, C.D., Nemani, R.R., and Running, S.W. (2003). Assessing the impact of urban land development on net primary productivity in the southeastern United States. *Remote Sensing Of Environment* **86**:401-410.

Nowak, D. (1996). Estimating leaf area and leaf biomass of open-grown deciduous urban trees. *Forest Science* **42**:504-507.

Nowak, D. and Crane, D. (2002). Carbon storage and sequestration by urban trees in the United States. *Environmental Pollution* **116**:381-389.

Nowak, D., Crane, D.E., Stevens, J.C. and Ibarra, M. (2002). Brooklyn's urban forest. General Technical Report NE-290, USDA Forest Service Northeastern Research Station, Newtown Square, PA.

Nowak, D.J., Rowntree, R.A., McPherson, E.G., Sisinni, S.M., Kerkmann, E.R. and Stevens, J.C. (1996). Measuring and analyzing urban tree cover. *Landscape and Urban Planning* **36**:49-57.

Pouyat, R. and Carreiro, M. (2003). Controls on mass loss and nitrogen dynamics of oak leaf litter along an urban-rural land-use gradient. *Oecologia* **135**:288-298.

Pouyat, R., Groffman, P., Yesilonis, I. and Hernandez, L. (2002). Soil carbon pools and fluxes in urban ecosystems. *Environmental Pollution* **116**:S107-S118.

Pouyat, R.V., McDonnell, M.J. and Pickett, S.T.A. (1995). Soil characteristics of oak stands along an urban-rural land-use gradient. *Journal of Environmental Quality* **24**:516-526.

Qian, Y., Bandaranayake, W., Parton, W., Mecham, B., Harivandi, M. and Mosier, A. (2003). Long-term effects of clipping and nitrogen management in turfgrass on soil organic carbon and nitrogen dynamics: The CENTURY model simulation. *Journal of Environmental Quality* **32**:1695-1700.

Qian, Y. and Follett, R. (2002). Assessing soil carbon sequestration in turfgrass systems using long-term soil testing data. *Agronomy Journal* **94**:930-935.

Raturi, S., Islam, K.R., Carroll, M.J. and Hill, R.L. (2004). Thatch and soil characteristics of cool- and warm-season turfgrasses. *Communications In Soil Science And Plant Analysis* **35**:2161-2176.

Smith, W.B. and Brand, G.J. (1983). Allometric biomass equations for 98 species of herbs, shrubs, and small trees. Research Note NC-299, USDA Forest Service North Central Forest Experiment Station, St. Paul, MN.

Theobald, D.M. (2004). Placing exurban land-use change in a human modification framework. *Frontiers in Ecology and the Environment* **2**:139-144.