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Climate Change Other Agriculture/Sinks/Land Uses [2]

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**Dialogue on Carbon Sinks
National Academy of Sciences
March 28, 2000, 9 AM – 4 PM**

Final Annotated Agenda

- 8:30-9:00 Continental Breakfast
- 9:00-9:10 Welcome (Frank Loy, Under Secretary of State for Global Affairs)
- 9:10-9:20 The role of science in foreign policymaking (John Boright, Executive Director, Office of International Affairs, National Academy of Sciences)
- 9:20-9:40 Introduction (Daniel Bodansky, Climate Change Coordinator, Department of State)
1. Overview of relevant provisions of Kyoto Protocol (Articles 3.3, 3.4, 3.7, 6, 12)
 2. Introduction to basic concepts and issues: human attribution, permanence, additionality, leakage, etc.
- 9:40-10:20 Overview of role of terrestrial sinks in the global carbon cycle (Richard Houghton, Woods Hole Research Center)
1. Brief overview of carbon cycle
 2. What are the principal terrestrial carbon pools and sinks? How do they work? What are their magnitudes (both globally and in the US)? What are their permanence/residence times?
 3. What is the long-term potential (both globally and for the US) of terrestrial carbon sinks to offset greenhouse gas emissions and thereby mitigate climate change?
 4. Other issues:
 - How much do carbon sinks vary naturally?
 - What other factors may influence terrestrial carbon sinks, either positively (e.g., carbon fertilization) or negatively (e.g., warming)?
- 10:20-10:40 Break
- 10:40-11:40 Data/measurement issues: how do we know what we know, and with what certainty? (Panel: Richard Birdsey, USDA; Linda Heath, USDA; Marlen Eve, USDA; Keith Paustian, Colorado State University)
1. What are the currently available sources of information about carbon sinks/pools (forests, agricultural soils, forest products, etc.)?

WCF above and beyond BTU?

- description of forestry inventory, national resources inventory
 - remote sensing
 - models to project future trends
 - description of models to determine how much carbon sequestered by forests and agricultural soils
2. Uncertainty
 - How much uncertainty is there about:
 - current inventory numbers?
 - projections of future numbers?
 - To what degree is uncertainty due to lack of scientific understanding vs. lack of data?
 3. What is the prognosis for our ability to measure carbon sinks during the first commitment period (2008-2012)?

11:40-12:25 Forestry (Steven Hamburg, Brown University)

1. What are the principal existing definitions of afforestation, reforestation and deforestation (Kyoto Protocol art. 3.3)?
 - Definitions of “forests” (based on land use, canopy cover, etc.) Is an internationally-agreed definition of “forestry” needed in order to define ARD?
 - What are the relevant parameters for defining ARD (e.g., land-use change, land use, canopy cover, plantings/cuttings)? Must afforestation and deforestation be defined in terms of land-use change, or could a definition be based on change in forest cover, or on planting and cutting, regardless of where it occurs?
 - Review of key definitions of reforestation (in particular, FAO vs. IPCC definitions)
 - Implications of different definitions
2. Forest management and conservation (Kyoto Protocol art. 3.4)
 - Role of forest management and conservation in sequestering carbon
 - How might forest management and conservation be brought into the Kyoto Protocol under Article 3.4?
3. How might we determine which forest sequestrations are (direct) human-induced?

12:30-1:00 Lunch

1:00-1:45 Agricultural soils (Bruce Babcock, Iowa State University)

1. What are the principal ways to sequester more carbon in agricultural soils?
2. How might we define these activities, in order to include them in the Kyoto Protocol under Article 3.4? Based on intensity of management activities? Based on specific management practices?

3. What is the physical and economic potential for carbon sequestration in agricultural soils?
4. In a system of full GHG accounting, what are the potential tradeoffs between additional carbon sequestrations in agricultural soils and increased emissions of GHGs (for example, through increased use of fertilizers)?

1:45-2:30 Project-based LULUCF activities (Jayant Sathaye, Lawrence Berkeley Laboratory)

1. What types of projects could be undertaken to sequester carbon in terrestrial systems?
 - Afforestation/reforestation
 - Forest conservation and management
 - Conservation tillage
 - Other
2. What is the potential for forestry and agricultural soil projects in:
 - Developed countries (under Article 6, joint implementation)?
 - Developing countries (under Article 12, CDM)?
3. Key issues raised by project-based activities
 - Permanence
 - Additionality/baselines
 - Leakage
 - Measurement and monitoring

2:30-2:45 Break

2:45-3:45 Dialogue/Discussion

Particular issues to focus on:

- Comprehensive carbon accounting vs. practice-based approaches
- Human attribution
- Permanence
- Leakage
- Additionality

3:45-3:55 Wrap up (David Sandalow, Assistant Secretary of State, Bureau of Oceans & International Environmental & Scientific Affairs)

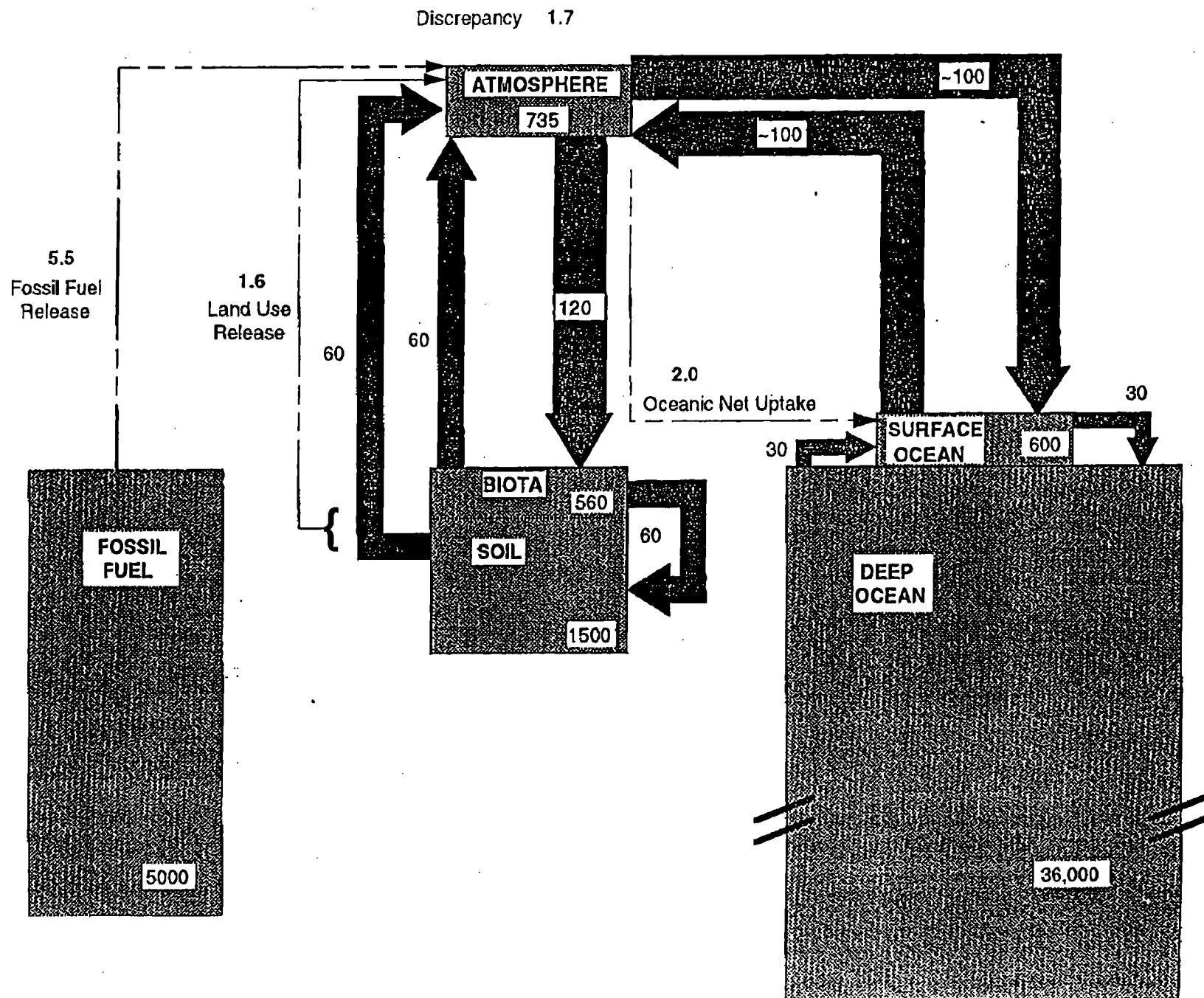
3:55-4:00 Closing Remarks (Frank Loy, Under Secretary of State for Global Affairs)

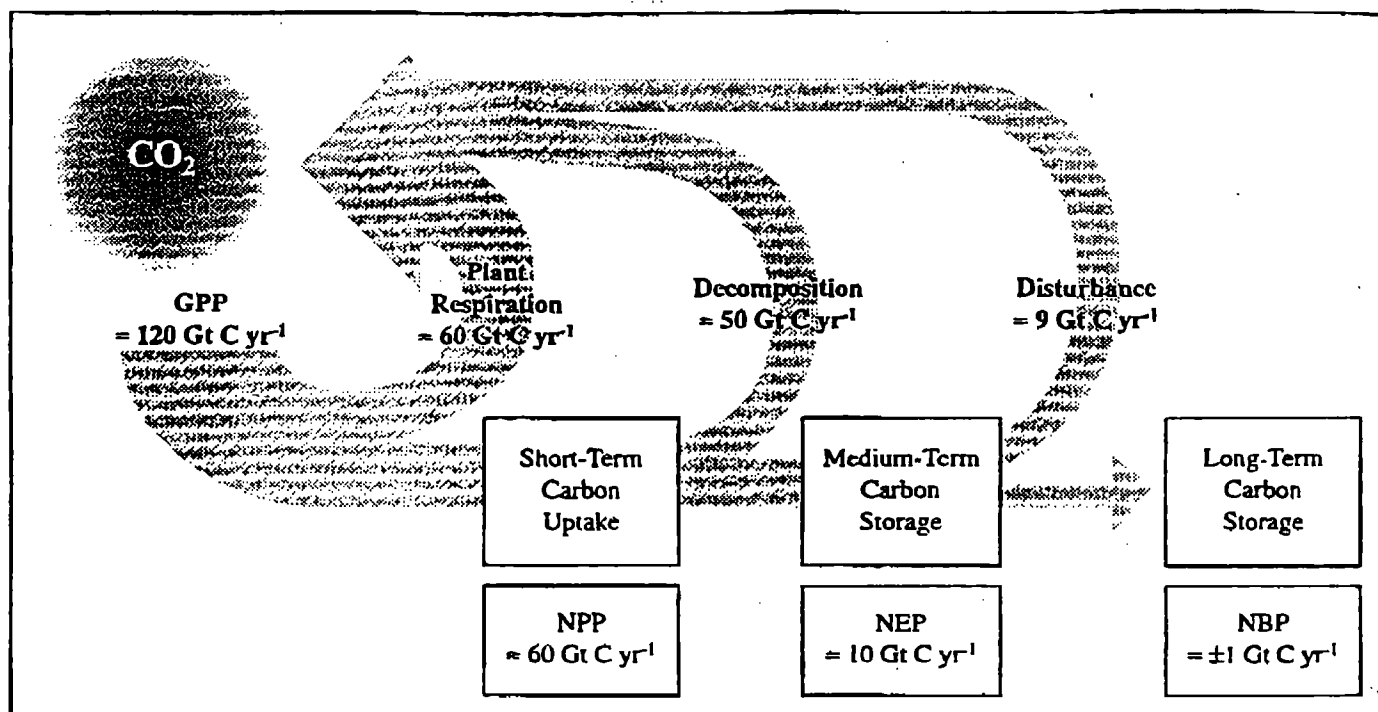
Dialogue on Carbon Sinks
Co-sponsored by the Department of State and
the National Academy of Sciences
March 28, 2000, 9 AM – 4 PM

Final Agenda

- | | |
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| 9:10-9:20 | The Role of Science in Foreign Policymaking (John Boright, Executive Director, Office of International Affairs, National Academy of Sciences) |
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| 1:45-2:30 | Project-based LULUCF activities (Jayant Sathaye, Lawrence Berkeley Laboratory) |
| 2:30-2:45 | Break |
| 2:45-3:45 | Roundtable Discussion |
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Dr. Richard Houghton
Presentation for Carbon Sinks Dialogue
-- Department of State & National Academy of Sciences
March 28, 2000





GLOBAL CARBON POOLS

(Billions of metric tons)

ATMOSPHERE	775
OCEAN	
SURFACE	600
DEEP	39,000
LAND	
BIOMASS	500
SOIL	2,000
FOSSIL FUELS	5,000

GLOBAL CARBON FLOWS

(Billions of metric tons/yr)

Ocean $\leftrightarrow$ Atmosphere	90
Land $\leftrightarrow$ Atmosphere (GPP)	120
Net Primary Productivity (NPP)	60
Net Ecosystem Productivity (NEP)	10
Net Biome Productivity (NBP)	<u>± 1</u>
Atmospheric increase	3.3
Fossil fuel emissions	5.5
Land-use change	2.0
Oceanic uptake	<u>-2.0</u>
Residual terrestrial sink	-2.2

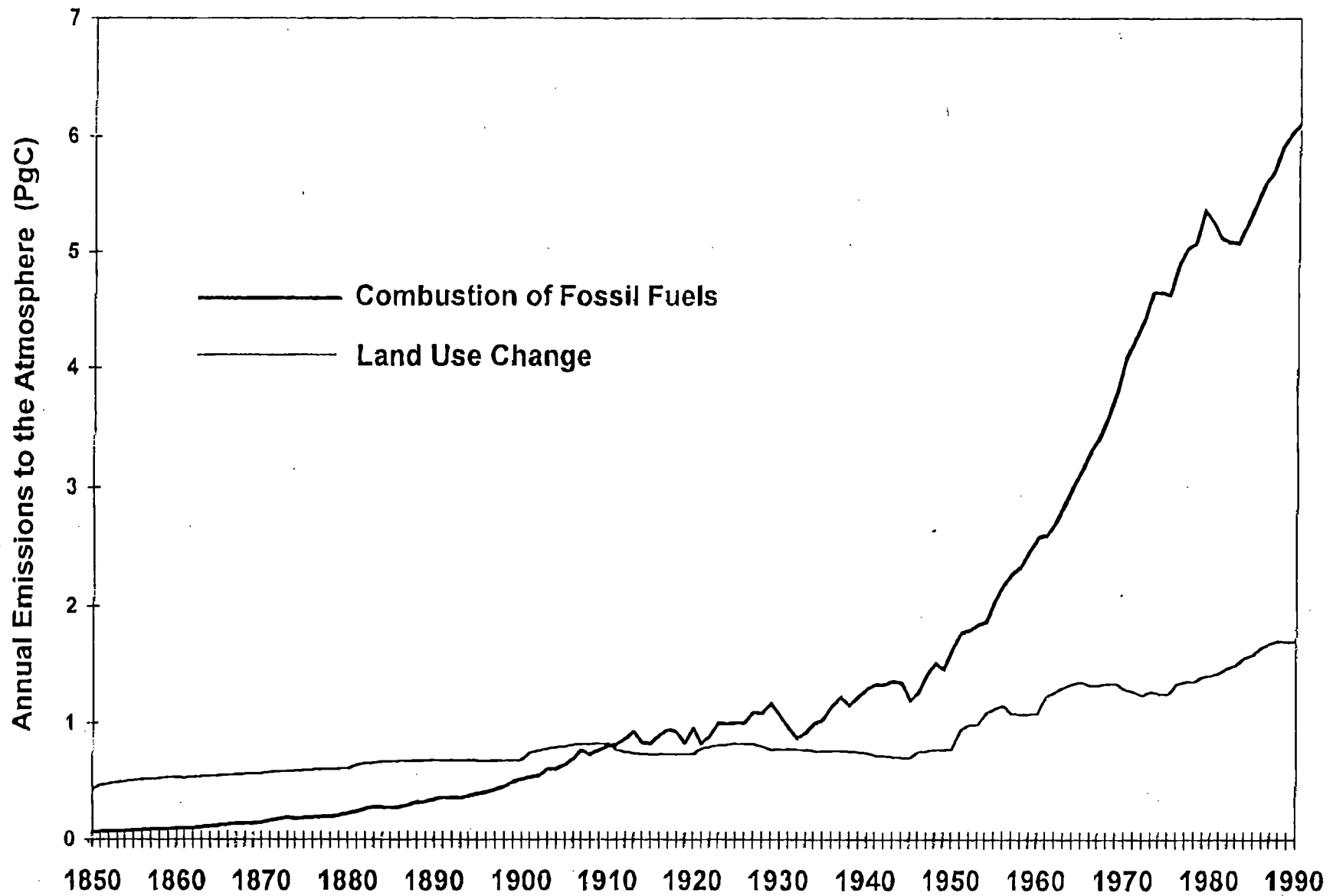
The Global Carbon Budget

Average annual fluxes of carbon (PgC yr⁻¹)

$$\begin{array}{ccccccc} \text{Atmospheric} & = & \text{Fossil} & + & \text{Net emissions} & - & \text{Oceanic} & - & \text{Residual} \\ \text{increase} & & \text{fuel} & & \text{from changes} & & \text{uptake} & & \text{terrestrial} \\ & & & & \text{in land use} & & & & \text{sink} \end{array}$$

$$3.3(\pm 0.2) = 5.5(\pm 0.5) + 2.0(\pm 0.8) - 2.0(\pm 0.8) - 2.2(\pm 1.3)^*$$

*An accumulation of about 0.6 ± 0.5 PgC yr⁻¹, not related to land-use change, has been observed in forests of the northern mid-latitudes and in forests of the neo-tropics.



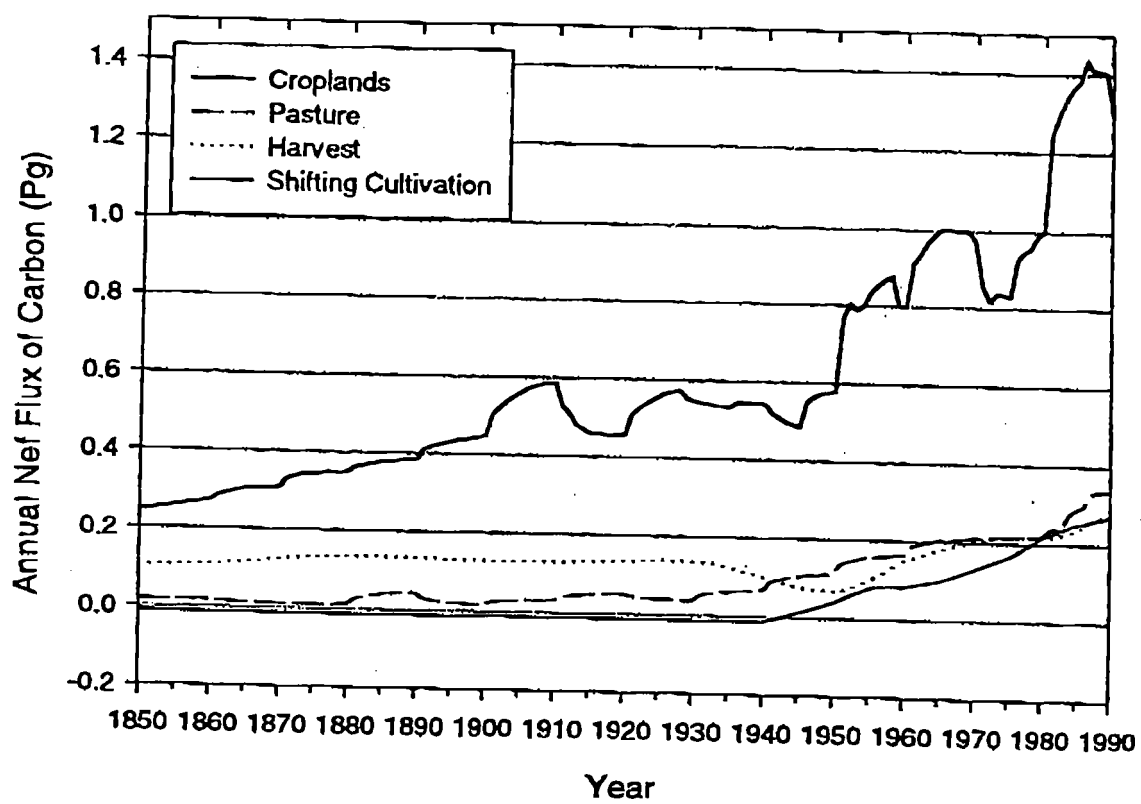


Fig. 2

GLOBAL ESTIMATES OF TERRESTRIAL SINKS and *SOURCES*

(PgC/yr)

Oceanic model inversions:

Net terrestrial sink of **0.2 (± 1.0)** (global)

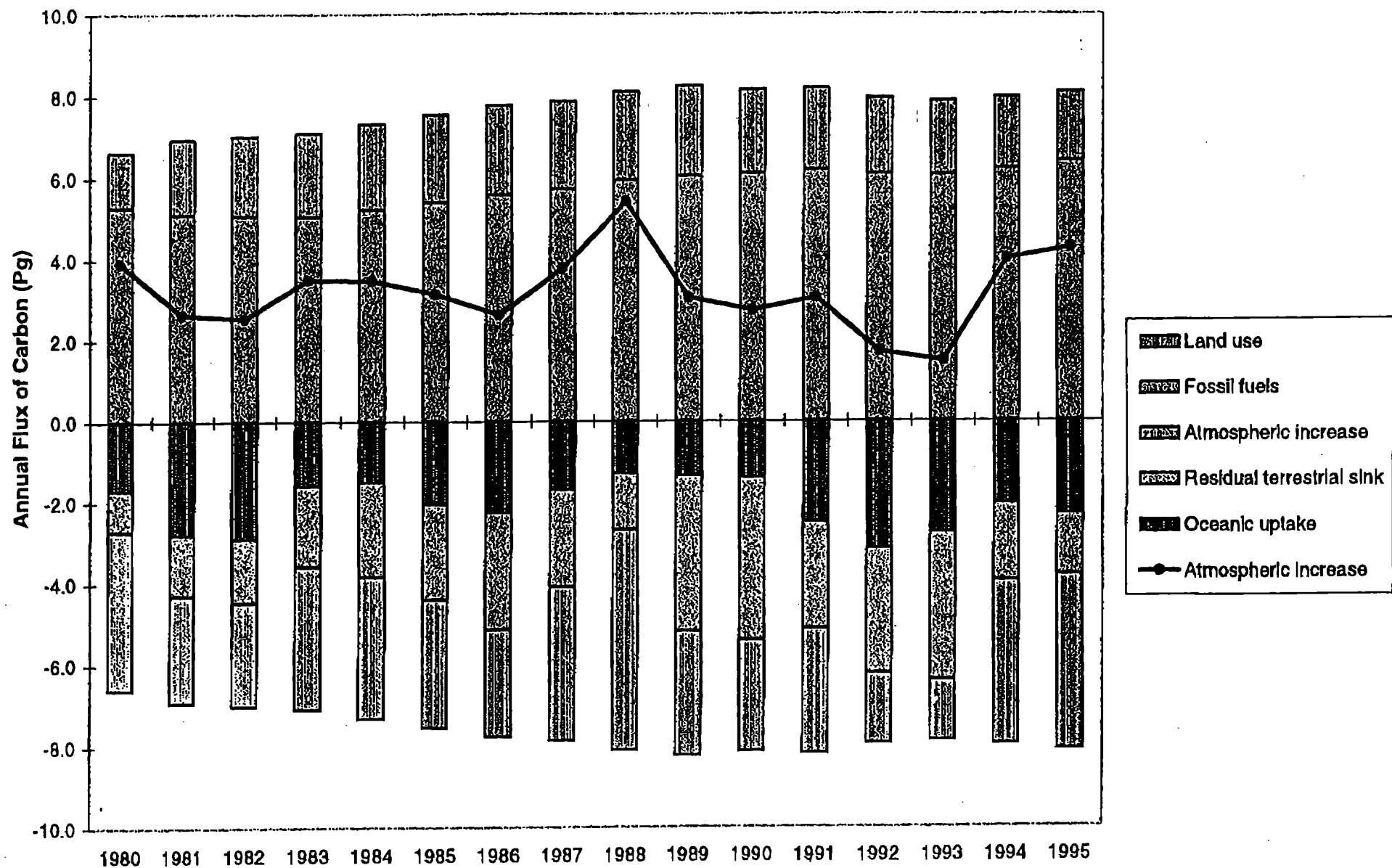
Analyses of land-use change:

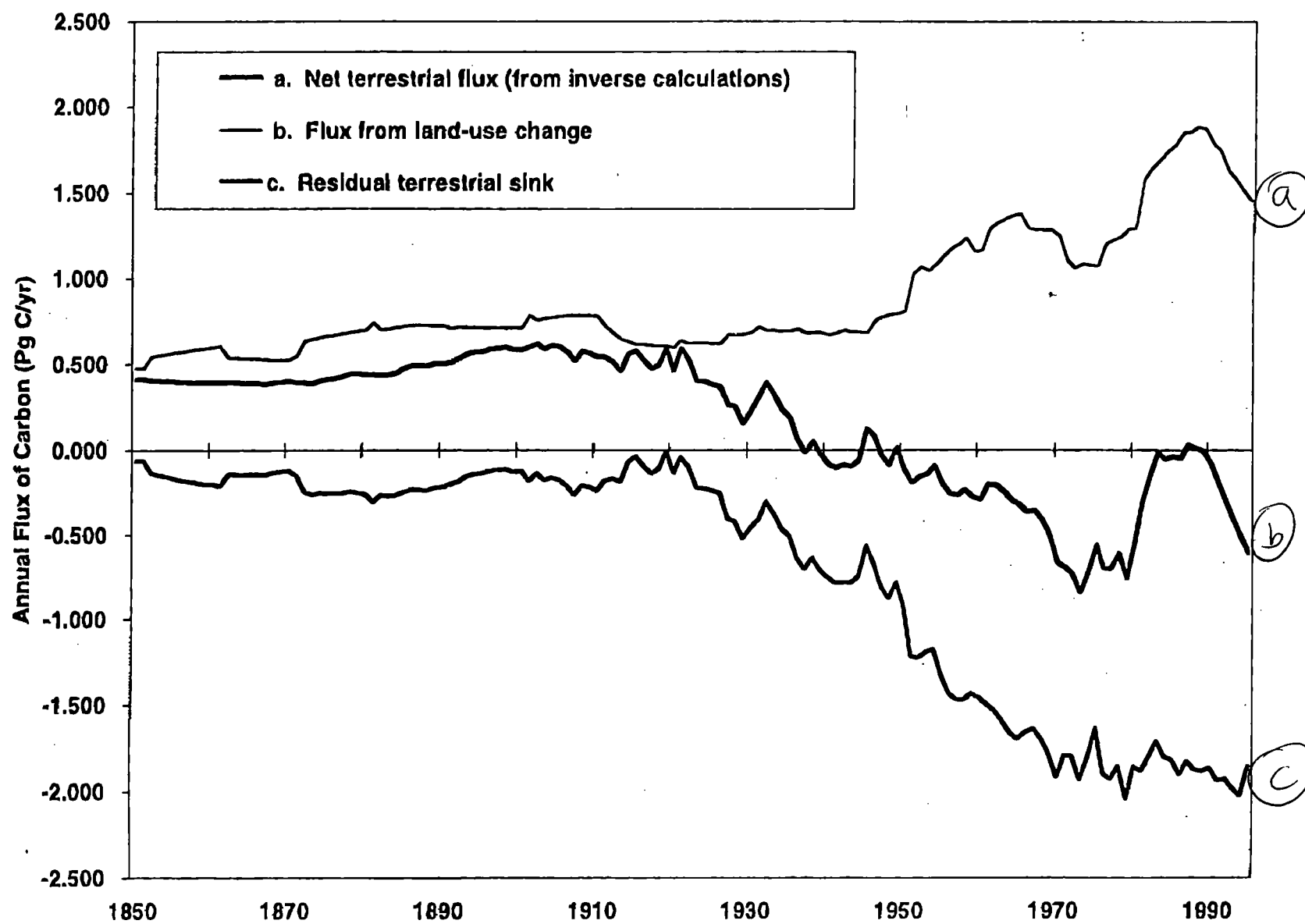
1.6 to 2.0 PgC/yr global source (direct human effect)

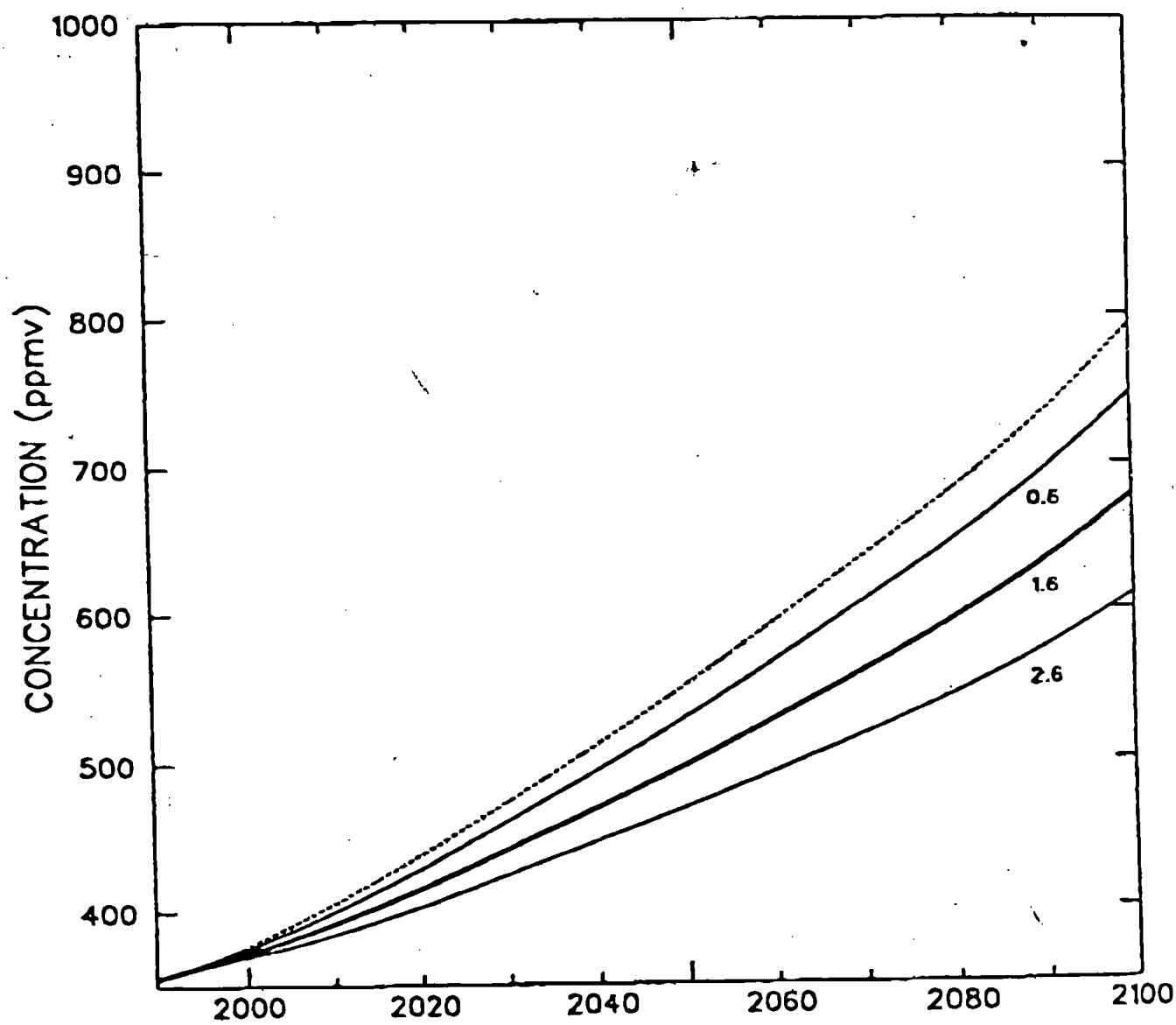
Thus, **1.8 to 2.2** PgC/yr sink elsewhere (indirectly related to human activity
or natural effect)

Atmospheric model inversions

Global	N. America	EurAsia	Tropics	Reference
2.0 (± 1.4)	1.7 (± 0.5)	0.1 (± 0.6)	0.2 (± 0.9)	Fan et al. 1998
0.7	0.5	0.2	0.0	Rayner et al. 1999
1.3 (± 1.6)	0.5	1.8	1.1	Bousquet et al. 1999
Land-use change				
1.7	0.2	0.1	1.8	Houghton 1999







(from Wigley 1993)

SOURCES AND SINKS OF CARBON in the 1980s (Billions of metric tons/yr = GtC/yr)

Fossil fuel	5.5	}	sources
Land use	1.6		

Atmos. Incr. - 3.3

Ocean	<u>-2.0</u>	}	sinks
Residual	-1.8		

Forestation potential

next 50 years: 1.5 ± 1.5 (60-87 GtC by 2050)
on $\sim 350 \times 10^6$ ha
(IPCC)

Estimates of the U.S. Terrestrial Sinks

METHOD	TgC yr ⁻¹	tC ha ⁻¹ yr ⁻¹
Land-use change	(37) 150 - 350	1.4
Forest inventories	106 - 202	
Ecosystem model (TEM)	78	
CO ₂ Flux		1.4 - 2.8
Atmospheric inversion	1700 ± 500 (500)	

U.S.A.
Flux of Carbon in 1980s (Millions tons C/yr)

	Net	Sources	Sinks
Croplands	2	92	90
Pastures	0	25	25
Wildfires	-63	81	144
Industrial harvests	27	94	67
Fuel wood harvests	-3	22	25
Subtotal	-37	314	348
Woody encroachment	-122		
Early fire suppression	-52		
Agricultural management	-138		
Total	-350		

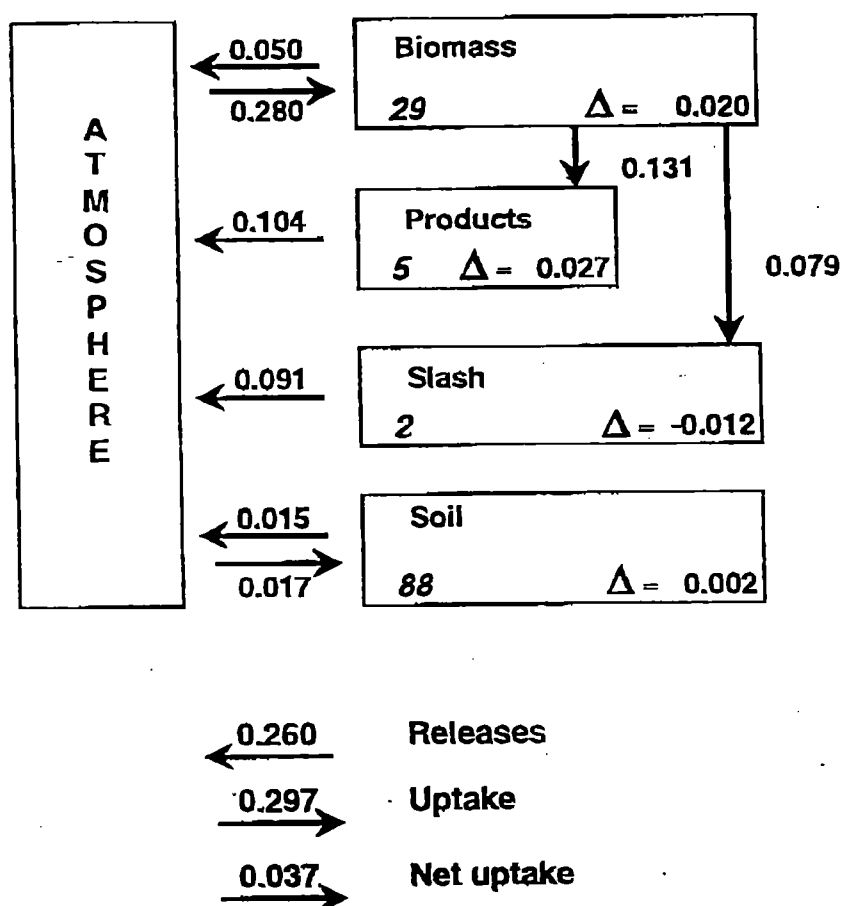


Figure 4 Houghton et al.

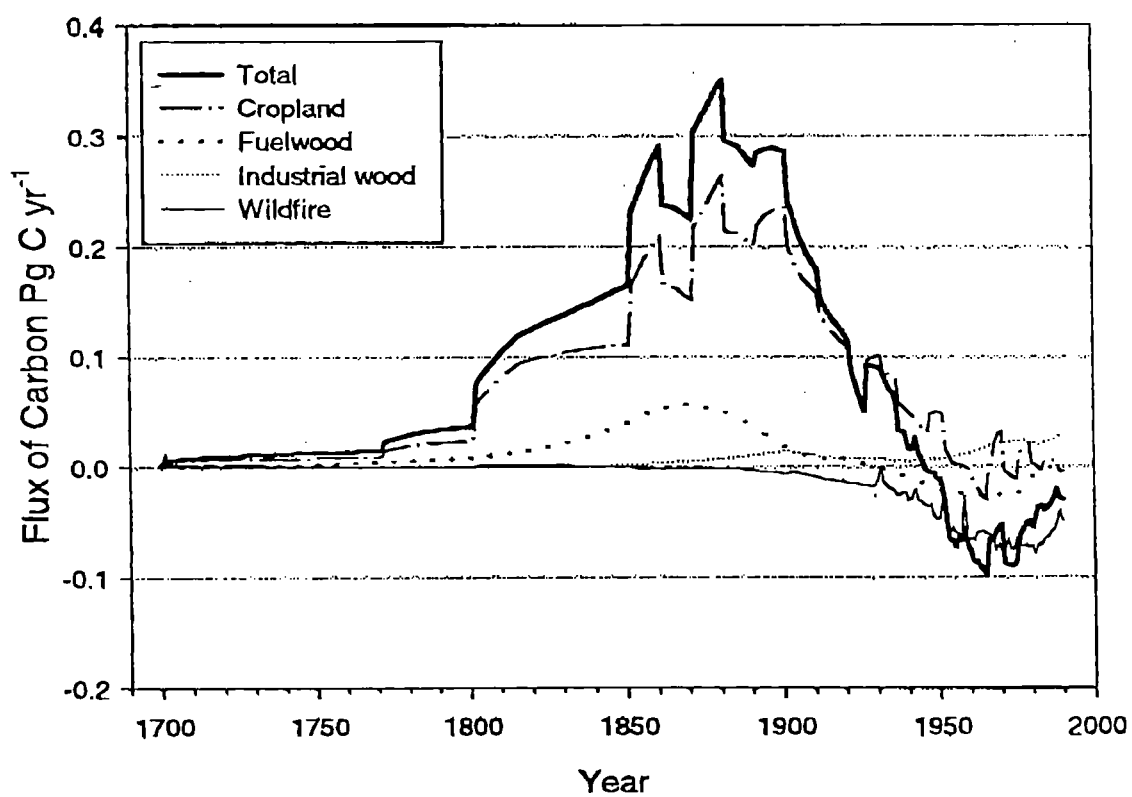


Figure 1 Houghton et al.

U.S.A.
TERRESTRIAL CARBON SINKS (TgC/yr)

	Forest Inventories		Land-use change
	Birdsey & Heath	Turner et al.	Houghton
Vegetation	-98	-63	-20
Wood products	72	-27	-27
Woody debris	-21	-16	12
Soils	-155	0	-2
Total	-202	-106	-37

SOURCES AND SINKS OF CARBON

(Billions metric tons = GtC)

1850-1990

Globe

Fossil fuel	~ 250	
Land use	~ 124	(108 from forests)

USA

Fossil fuel	~ 77	
Land use	~ 25	(22 from forests)

~1990 (Billions metric tons/yr = GtC/yr)

Globe

Fossil fuel	~ 6.3	
Land use	~ 1.6	{ tropics: + 1.7
		{ mid-latitudes: - 0.1

USA

Fossil fuel	~ 1.3	
Land use	~ - 0.25	

Dialogue on Carbon Sinks

March 28, 2000

Biographical and contact information of presenters

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Dr. Bruce Babcock is the director of the Center for Agricultural and Rural Development and is Professor of Economics at Iowa State University. Prof. Babcock received B.S. and M.S. degrees from the University of California at Davis in 1980 and 1981 and his Ph.D. in Agricultural and Resource Economics from the University of California, Berkeley, in 1987. He was an assistant professor at North Carolina State University before moving to Iowa State in 1990. Prof. Babcock has published extensively on the economics of agricultural policy and the adoption of new agricultural technologies. His recent focus of research emphasizes development of innovative risk-sharing contracts that can induce farmers to adopt environmentally-friendly production practices.

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Dr. Birdsey received his Ph.D. in Quantitative Methods from the State University of New York, College of Environmental Science and Forestry. He was a Peace Corps Forester in Ecuador, a Research Forester with the Forest Service in the Forest Inventory and Analysis Project at the Southern Research Station, and a member of the Forest Inventory and Analysis Staff in the Washington Office of the Forest Service. He has been Program Manager for Global Change Research for the last ten years at the Northeastern and North Central Research Stations. In his current role as Program Manager, Dr. Birdsey is coordinating a national research effort to analyze the impacts of international protocols on carbon accounting for the U.S., and to identify forest management strategies to increase carbon sequestration.

Dr. Birdsey is a specialist in quantitative methods for large-scale forest inventories; he has pioneered the development of methods to estimate national carbon budgets for forested lands from forest inventory data. He is a major contributor to the ongoing inventory of U.S. greenhouse gases and sinks compiled by USDA, EPA, and DOE. He is a cooperator with the

Sukachev Institute of the Russian Academy of Sciences in a project to estimate the Russian carbon budget. Dr. Birdsey has compiled and published estimates of historical and prospective U.S. forest carbon sources and sinks, and analyzed options for increasing the role of U.S. forests as carbon sinks.

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Dr. Marlen Eve is a Soil Scientist with USDA-ARS Soil Plant Nutrient Research Unit in Fort Collins, Colorado, and holds a joint position with the Natural Resource Ecology Laboratory at Colorado State University as a Research Associate. Dr. Eve is working on estimating regional to national scale changes in soil organic carbon using the IPCC inventory procedure. The primary focus of his research is changes in soil carbon resulting from changes in land use and land management.

Dr. Eve has a B.S. in Soils from Montana State University, and an M.A.G. and Ph.D. from New Mexico State University in applying remote sensing and GIS techniques to map, monitor, and model landscape processes.

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Dr. Hamburg received his Ph.D. in Forest Ecology from Yale University. Following post-doctoral study at Stanford University, he was a member of the faculty of the Department of Systematics and Ecology at the University of Kansas from 1985 to 1994, where he was Environmental Ombudsman and Director of the Environmental Studies Program from 1990 to 1994. He was a Bullard Fellow at Harvard University in 1991-1992, and a Senior Ecologist with the Environmental Defense Fund in 1994-1995. Since 1994 he has been Ittleson Associate Professor of Environmental Studies at Brown University. He contributed to the IPCC Second Assessment as Review Editor, was the Lead Author of the IPCC Special Report on Land Use, Land Use Change, and Forestry, and co-wrote a UNEP-sponsored report on linkages between global environmental issues and human needs. Prof. Hamburg has published many articles on the impacts of anthropogenic disturbances on forest ecosystems.

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Dr. Richard Houghton is an ecologist with interests in the role that terrestrial ecosystems play in climate change and the global carbon cycle. He coordinates the Woods Hole Research Center's efforts to understand the problems of global warming and climate change, especially the role that biotic systems play in this accelerating process. He has a Ph.D. in ecology from the State University of New York at Stony Brook. He has worked on the global carbon cycle for over 20 years, during which time he has held positions as Assistant Scientist at the Ecosystems Center of the Marine Biological Laboratory and as Research Associate at Brookhaven National Laboratory. His research has concentrated on determining historic and current sources and sinks of carbon from changes in land use (e.g., deforestation, reforestation, and timber harvest). He has participated in several IPCC scientific assessments of climate change and, most recently, in the IPCC Special Report on Land Use, Land-Use Change, and Forestry.

KEITH PAUSTIAN

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Dr. Keith Paustian's main fields of interest include agroecosystem ecology, soil organic matter dynamics, nitrogen cycling, simulation modeling, and global change. He has written more than 70 journal articles and book chapters on these topics. He is currently leading projects to assess soil carbon sequestration in several states, including Iowa, Indiana, Virginia, and Mississippi, and to develop U.S. inventories of carbon emissions and sequestration of carbon in soil. His research also involves development of ecosystem and economic assessments to advise policy makers on climate change mitigation.

He was co-chair of an IPCC workgroup on developing methodologies for estimating soil carbon dioxide emissions as part of the IPCC Guidelines for National Greenhouse Gas Inventories. He is currently a Lead Author on an IPCC special report evaluating carbon sinks as a mitigation option for greenhouse gas mitigation. He was also a member of the IPCC Working Group II on Agricultural Options for Mitigation of Greenhouse Gas Emissions and a member of the IGBP/GCTE Soil Organic Matter Scientific Steering Committee. He was an editor of a recent book entitled Soil Organic Matter in Temperate Agroecosystems: Long-term Experiments in North America, and of two special issues on soil carbon sequestration in the journals *Soil Tillage Research* and *Climatic Change*.

JAYANT ANANT SATHAYE

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Dr. Jayant Sathaye is internationally recognized for his work on land-use change and forestry, energy demand and supply, and greenhouse gas emissions in developing countries. He received his Ph.D. in Environmental Engineering from the University of California, Irvine. His current interests include the role of carbon sinks and their interpretation in the Kyoto Protocol, industrial energy use in developing countries, technological change and technology transfer to developing countries, long-term scenarios of greenhouse gas emissions, and the potential to slow emissions growth. In recent years, he has organized several training and information workshops, conducted studies, and written papers and reports on these topics. He has been a guest editor of eight special journal issues on climate change.

Dr. Sathaye has published widely in major energy and environment journals and authored over one hundred and fifty publications on these topics. He has been a Convening Lead Author, Section Leader, and Principal Lead Author on six publications of the Intergovernmental Panel on Climate Change since 1990. Dr. Sathaye has also led studies of regional and national energy strategies and their impact on local and global environment. He has lectured and consulted internationally in Asia and Africa for the United Nations, multilateral development banks, and other international organizations.

Terrestrial Carbon Sinks and the Kyoto Protocol

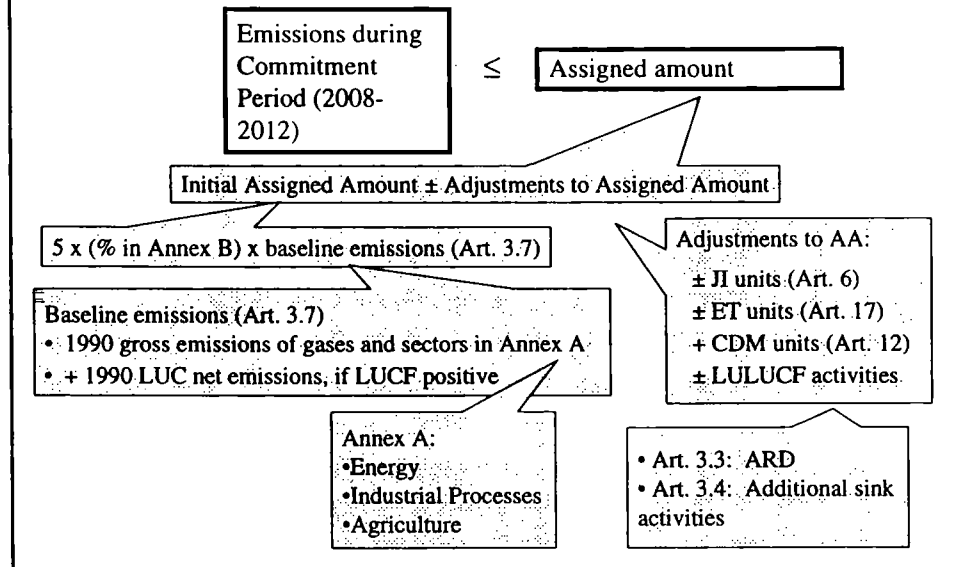
Daniel Bodansky
Department of State

March 28, 2000

Introduction

- Kyoto Protocol mostly deals with emissions from energy and industrial processes
- Land-use, land-use change and forestry (LULUCF) generally left out of Kyoto, except for a few limited provisions: Arts. 3.3, 3.4, 3.7, 6
 - ◆ Note that emissions (but not sequestrations) from agricultural soils included
- Issue: How sinks should be included in Kyoto??

Kyoto Accounting Equation



Kyoto Sink Provisions

- Article 3.3
 - ◆ Certain LULUCF activities are already included in Protocol: afforestation, reforestation and deforestation (ARD).
- Article 3.4
 - ◆ COP/MOP may choose to include additional LULUCF activities.
- Article 6
 - ◆ Sinks projects may generate JI units.

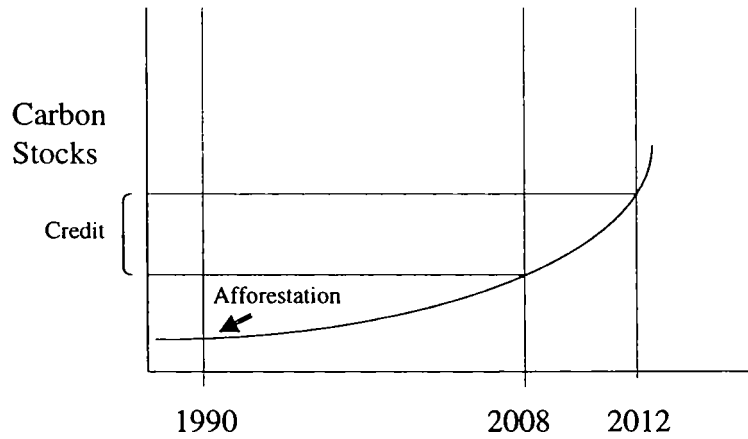
Kyoto Sink Provisions: Article 3.3

- Includes only afforestation, reforestation and deforestation (ARD).
- These activities included only if occur since 1990.
- Count changes in carbon stock during commitment period (i.e., 2008-2012).

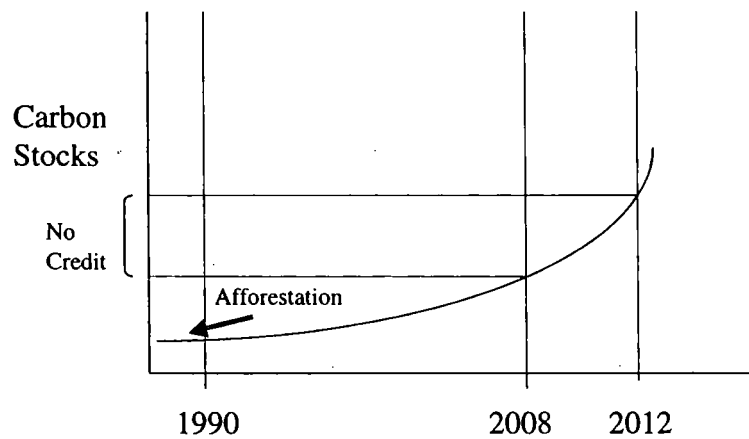
Counting Sinks under Article 3.3

- | | |
|---|--|
| <ul style="list-style-type: none">■ Step 1: Trigger - Human activity after 1990 creates Kyoto Land<ul style="list-style-type: none">◆ Article 3.3<ul style="list-style-type: none">✦ Afforestation✦ Deforestation✦ Reforestation | <ul style="list-style-type: none">■ Step 2: Accounting of carbon stock changes on Kyoto Land during the commitment period (2008-2012) |
|---|--|

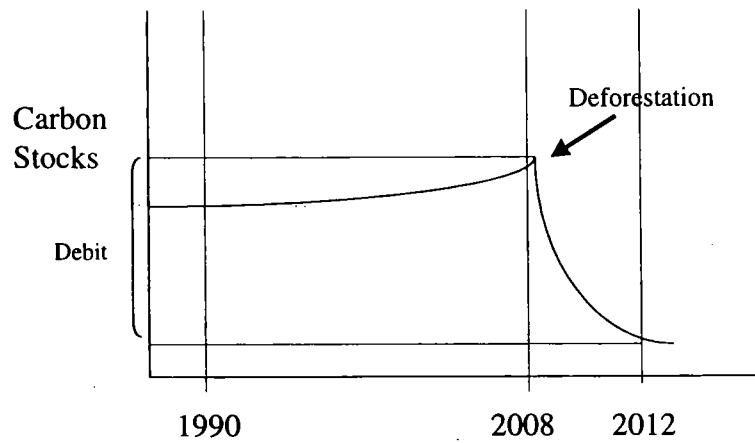
Afforestation after 1990



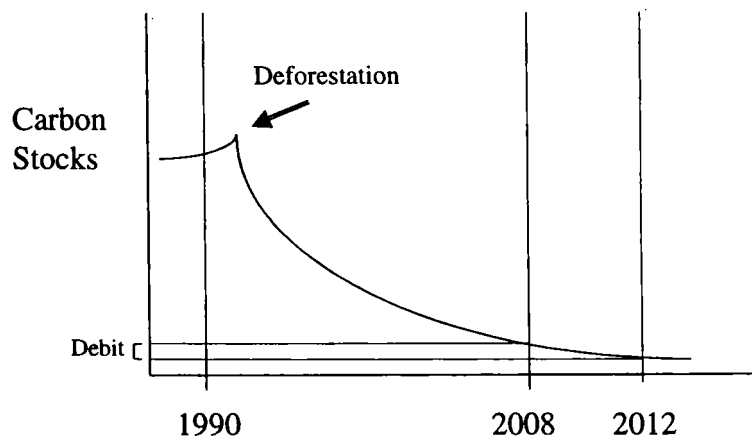
Afforestation before 1990



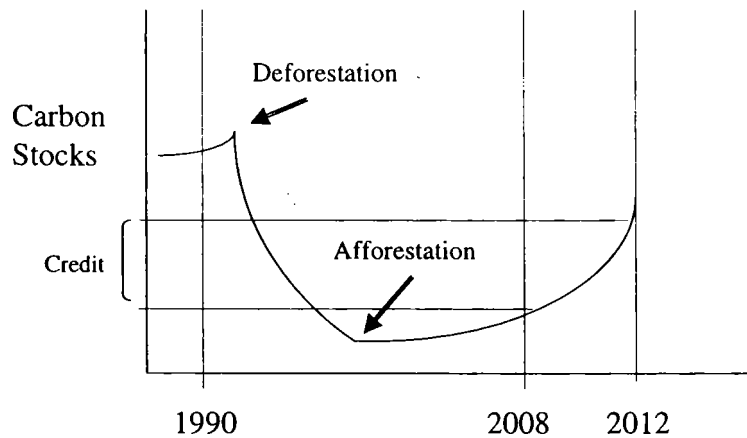
Deforestation during the Commitment Period



Deforestation before the Commitment Period



Deforestation followed by Afforestation



Kyoto Sink Provisions: Article 3.4

- COP/MOP may decide to include additional LULUCF activities.
 - ◆ Activities could be defined:
 - ✦ Broadly: e.g., forest conservation and management, cropland management
 - ✦ Narrowly, in terms of specific management practices: e.g., pest control, conservation tillage
- Decision shall apply in second and subsequent commitment periods (i.e., post-2012).
- Parties may choose to apply decision for first commitment period (2008-2012) for activities taking place since 1990.

Kyoto Sink Provisions: Article 3.4

- US has supported, as a goal, comprehensive carbon stock accounting
- Criteria for adding LULUCF activities include:
 - ◆ Level of uncertainties
 - ◆ Transparency in reporting
 - ◆ Verifiability

Issues for Decision at COP-6

- **Art. 3.3: Meaning of:**
 - ◆ afforestation
 - ◆ reforestation
 - ◆ deforestation
- **Article 3.4: Whether to include additional LULUCF activities and, if so, which ones?**
 - ◆ Forest conservation and management?
 - ◆ Agricultural soils?
- **Article 12: Whether to include sink projects in the Clean Development Mechanism (CDM)?**

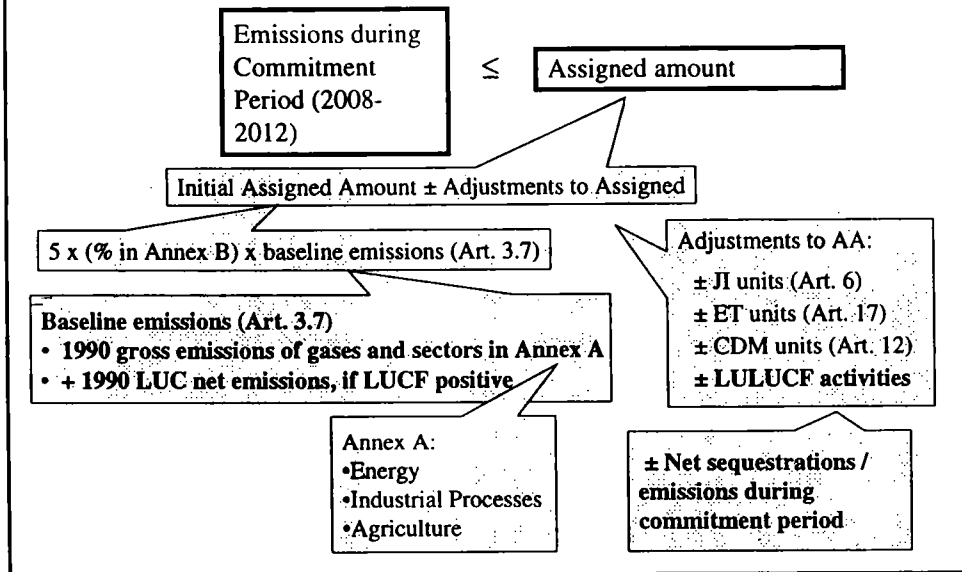
Time Line

- April 17-20: Perth ministerial
- July 10-12: Workshop on IPCC Special Report
- August 1: Submissions due with proposed definitions and additional activities
- September: Beginning of negotiations
- November: COP-6

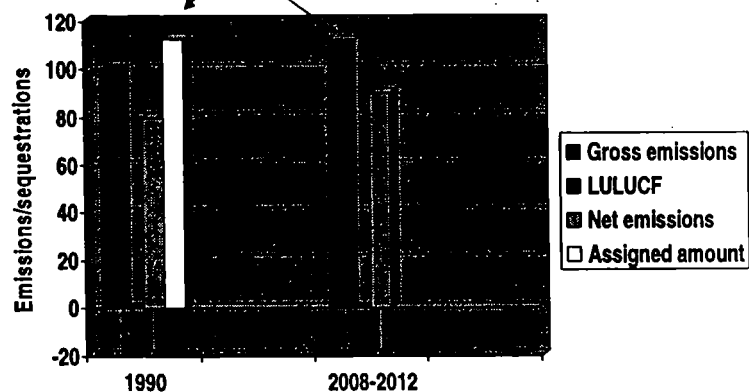
Specific Issues

- Additionality
- Human attribution
- Permanence

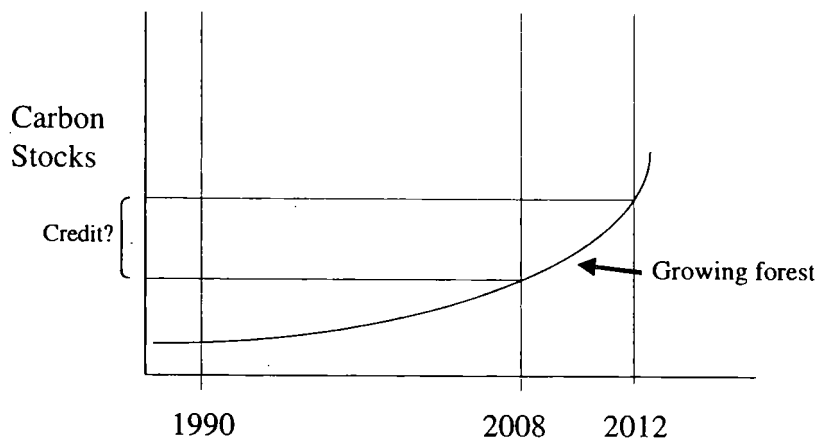
Kyoto Accounting Equation: Gross-Net vs. Net-Net Accounting



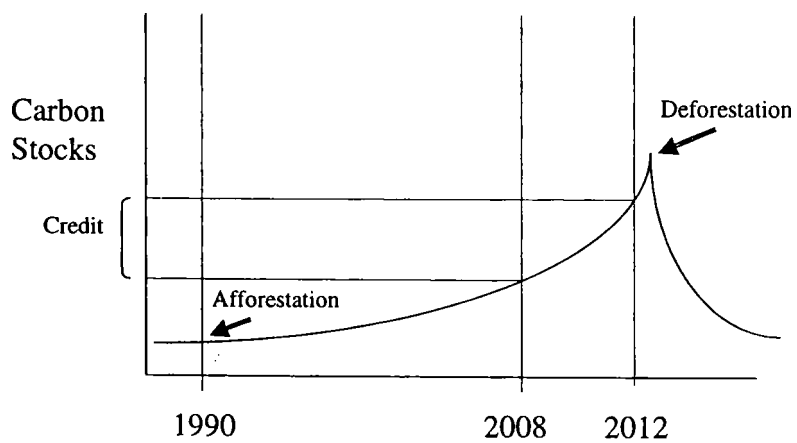
Gross-Net Accounting: Additionality?



Human attribution



Permanence/Durability



**Forest Inventory Methods
and Carbon Analysis**

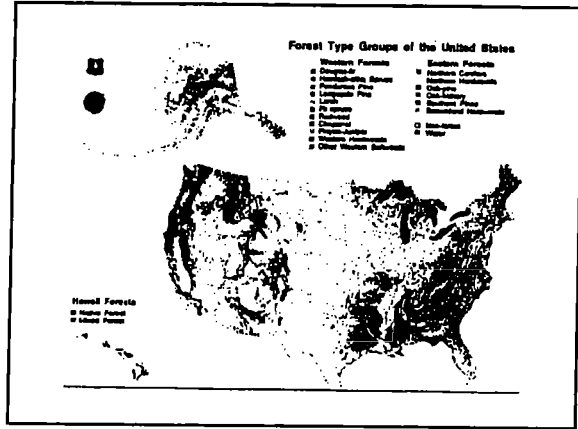
**Richard A. Birdsey
Linda S. Heath
USDA Forest Service
Northeastern Research Station**

Northeastern Research Station

Forest Carbon Pools

- **Forest ecosystems**
 - Tree, understory, forest floor, soil, dead wood (including logging residues)
- **Harvested wood**
 - Products, landfills, energy, emissions
(Examples of products are lumber, plywood, paper)

- **Forest ecosystems**
 - Tree, understory, forest floor, soil, dead wood (including logging residues)
- **Harvested wood**
 - Products, landfills, energy, emissions
(Examples of products are lumber, plywood, paper)



Inventory Sample Design

- **Phase One – Remote Sensing to Stratify Forest Area**
 - 3,000,000 forest sample points, each equals 200-300 acres
- **Phase Two – Ground Sampling of Forest Attributes**
 - 120,000 forest sample points, each equals 5000-6000 acres
- **Phase Three – Forest Health Monitoring**
 - 4,500 forest sample points, each equals 95,000 acres

- **Phase One – Remote Sensing to Stratify Forest Area**
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- **Phase Three – Forest Health Monitoring**
 - 4,500 forest sample points, each equals 95,000 acres

Phase One – Remote Sensing

Source: NAPP 1:40,000 color infrared photography

Sample Points: 16 photo points located systematically over the "effective area" of each photo.

Measurement: land cover

Note: in process of shifting to satellite data



Phase Two – Field Sampling

Five-Year Panel

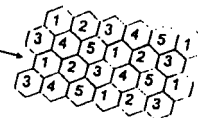
- Year One
- Year Two
- Year Three
- Year Four
- Year Five

Sample Intensity = 1 sample location
per 6,000 acres of land

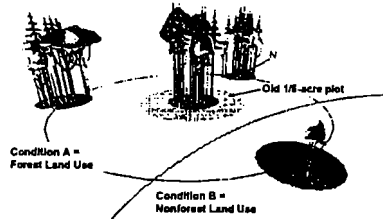
Inventory Cycle Length = Five years or
20 percent of the sample locations
each year

Five-Year Panel

- ☐ Year One
- ☐ Year Two
- ☐ Year Three
- ☒ Year Four
- ☐ Year Five



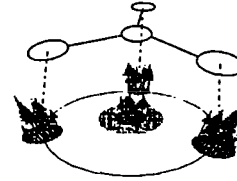
Phase Two Sample Location Design



Plot measurements: age, disturbance, owner, physiography, etc.

Tree measurements: species, dimensions, damage, etc.

Phase Three – Forest Health Monitoring



- FHM and FIA sample locations are co-located
- Additional data: crown condition, soils, understory, coarse woody debris, etc.

Forest Inventory Estimates as a Basis for Carbon Analysis (Trends by State and Region)

- Area by land class (reconciled with NRI)
- Area by forest type, owner, age class
- Tree volume by species and size class
- Tree biomass by species and size class

Error of Forest Inventory Estimates Southeast Region – 95% Confidence

(million m³)

Estimate	Value Range	Percent Error
Current volume	3415 to 3495	1
Net growth	125 to 129	2
Removals	113 to 121	3
Volume change	7 to 15	40

Includes errors of sampling, regression, and measurement

How estimate carbon?

Carbon stock = CARBON/AREA times AREA

Carbon stock change =

C stock at time 2 minus C stock at time 1

- Estimated values can be obtained from measured data or from using models•

Forest ecosystem pools - Tree

- TREE
 - Calculate carbon from volume or directly from tree data taken from the USDA Forest Service inventories

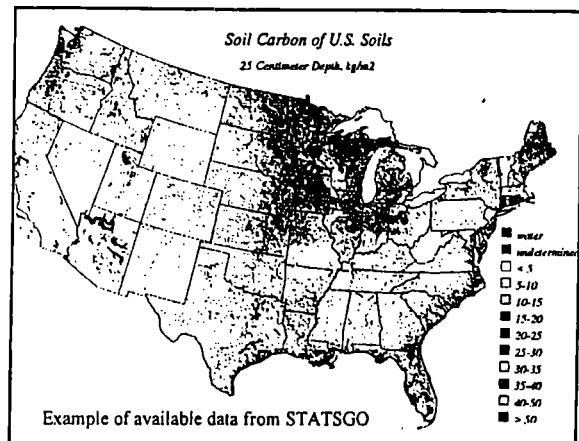
Example

93.2 million cu ft of Douglas-fir =

1,408 million lbs C

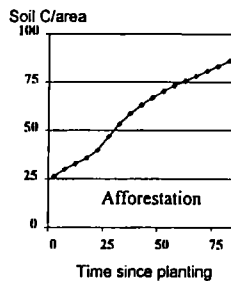
Forest ecosystem C pool - Soil

- USDA NRCS STATSGO or NATSGO soils databases. Based heavily on agricultural soils. In the future, FHM plot data.
- May be more accurate to model estimates based on combination of data and ecological studies



Forest ecosystem C pool - Soil

- Changes in soil stocks can be modeled based on previous land use

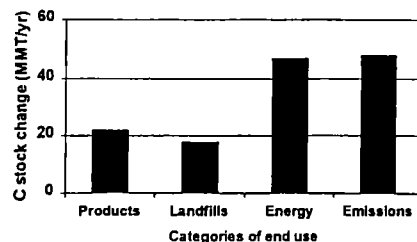


Carbon in harvested wood

- Removals data
 - Growing stock harvests, other removals
- Production data
 - Lumber, plywood, paper, etc

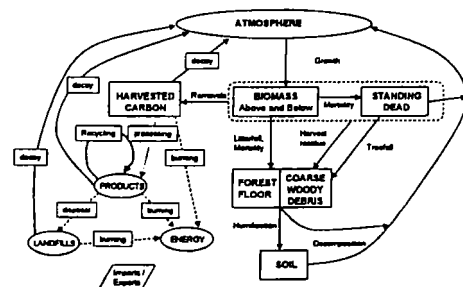
Sources: USDA Forest Service, Department of Commerce

Example: C in harvested wood products, 1990



Source: Heath and others (1996)

Forest sector carbon flows



Quantifying Changes in Carbon Storage in U.S. Soils

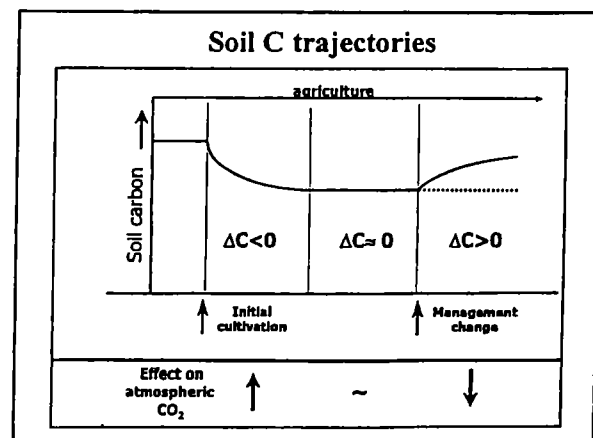
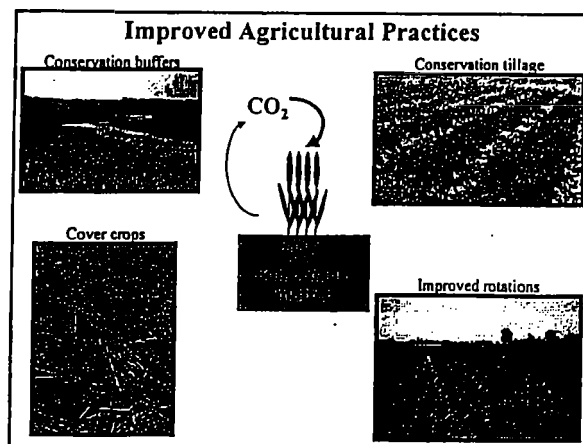
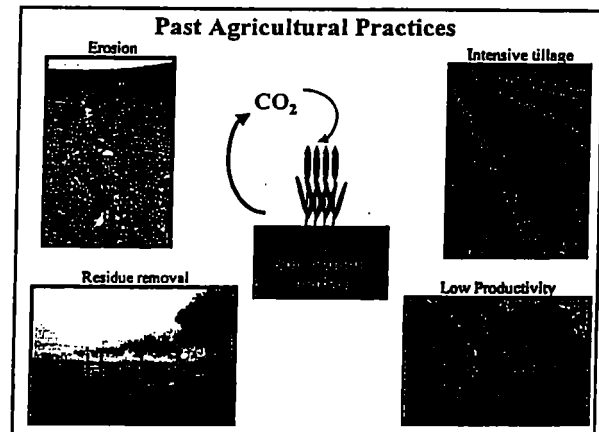
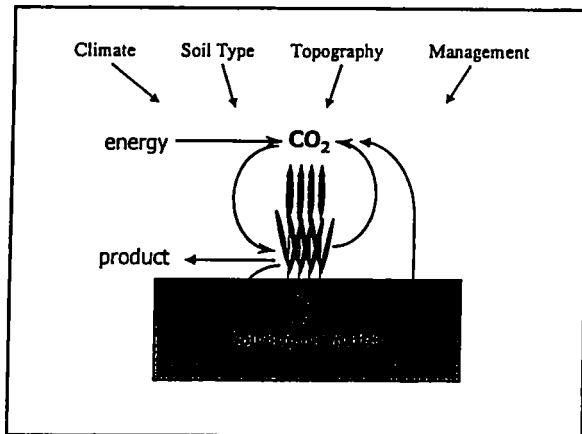
Marlen D. Eve^{1,2}
 Ronald F. Follett¹
 Keith Paustian²

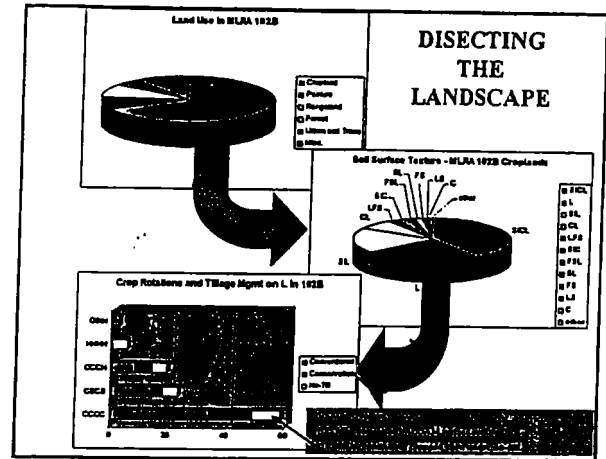
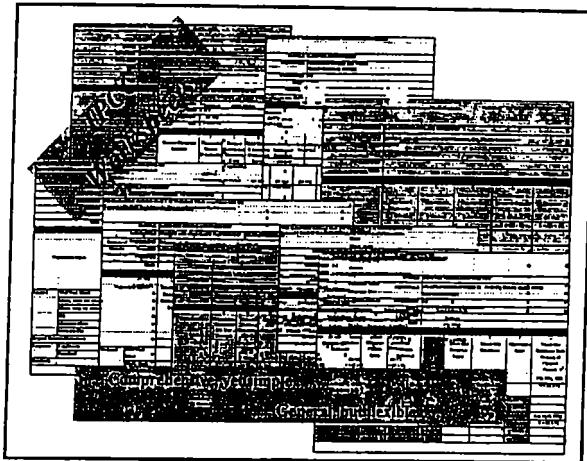
¹ USDA-ARS Soil Plant Nutrient Research Unit, Fort Collins, CO
² Natural Resources Ecology Laboratory, Colorado State University,
 Fort Collins, CO

TERRESTRIAL CARBON MODELING PROJECT

Objectives

- ✦ Estimate changes in soil Carbon storage (i.e. net CO₂ flux) in U.S. croplands
- ✦ Evaluate the differences in results between IPCC and a dynamic simulation model (CENTURY) approach,
- ✦ Investigate C storage under Business-As-Usual and potential scenarios and,
- ✦ Evaluate uncertainty associated with input data, default values, and spatial aggregation.





USDA-NRCS National Resources Inventory (NRI) Data

- ✦ Over 800,000 field sites across the conterminous U.S.
- ✦ Data collected every 5 years
- ✦ Associated soils database linked to NRI
- ✦ Contains land use, cropping history, soils, irrigation, CRP, and other information useful in a national C inventory

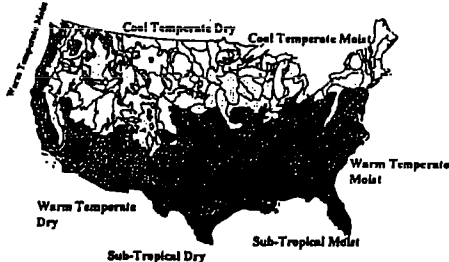
Data Aggregation

Group MLRA's into IPCC climatic regions using temperature and precipitation based on PRISM.

Group soils by soil order into the IPCC categories.

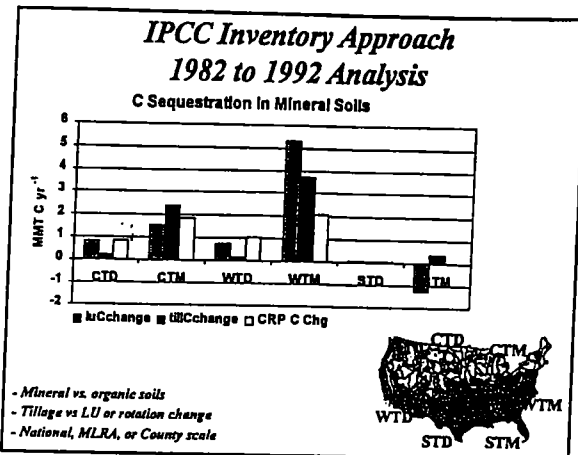
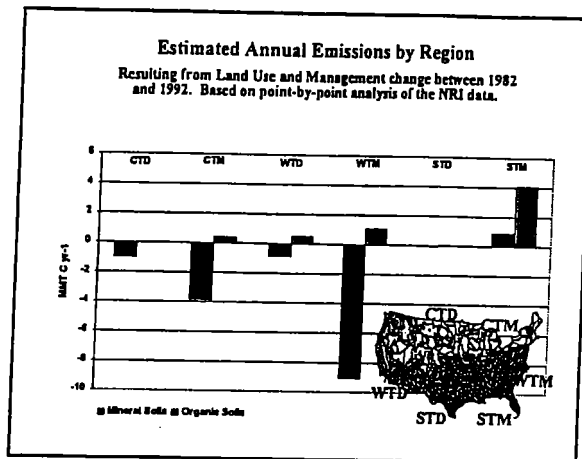
Group land use and management data from NRI into set categories.

Climatic Regions of the U.S.
Delineated using PRISM average precipitation and temperature summarized by MLRA according to the IPCC region definitions.



LAND USE Groupings

Agricultural Land	"No-Till" "Reduced Till" and "Conventional Till"	Irrigated Cropland Continuous Row Crops Cont. Row Crops/Small Grains Continuous Small Grains Row Crop - Fallow Row Crop/Small Grain - Fallow Small Grains - Fallow Small Grains - Small Grains - Fallow Row Crop - Hay/Pasture Row Crop/Small Grains - Hay/Pasture Small Grains - Hay/Pasture Continuous Hay Continuous Pasture Vegetables in Rotation Rice in Rotation Low Residue Annuals (ie cotton, tobacco) Perennial and/or Horticultural Crops Conservation Reserve Program (CRP)
Rangeland		
Forest		
Urban Land		
Water		
Misc. Non Cropland		
Federal Land		



Limitations

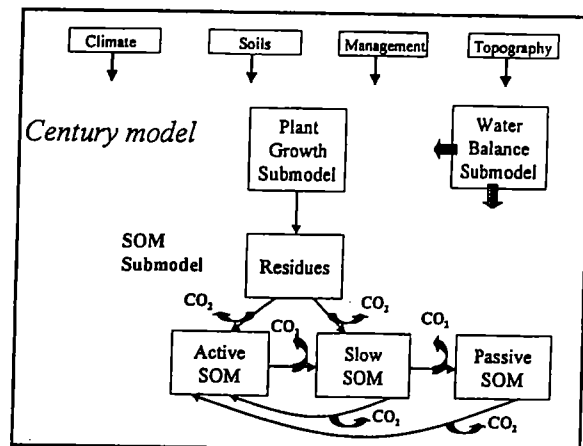
- ❖ Difficult to incorporate baseline trends from long-term land use/management changes
- ❖ Assumes 1982 is a steady-state starting point
- ❖ C sequestration in sediments is not considered
- ❖ Difficult to conduct an annual inventory from 5-year interval inputs
- ❖ Changes in C stocks are credited to the inventory period in which the change occurs while actual changes in soil C may not be realized until later.

Dynamic Simulation Model Approach (CENTURY)

Advantages:

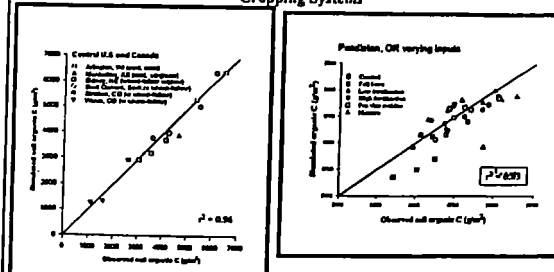
Can more efficiently simulate annual rates of change rather than ascribing an average annual rate to the entire inventory period.

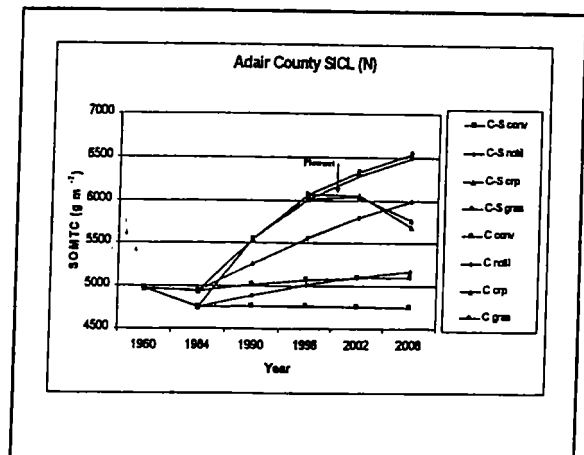
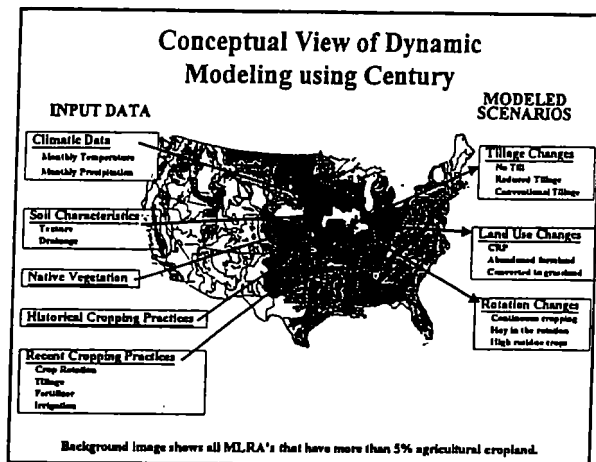
Capable of capturing more underlying changes such as the effects of historical change, and changes not related to changes in agricultural management (I.e. baseline trends).



EXAMPLES OF CENTURY MODEL VALIDATION

Cropping Systems





ESTIMATING UNCERTAINTY

Sources of Error

- ✦ In input data (e.g. soil properties, mgmt data)
- ✦ In rate estimates
- ✦ In spatial aggregation

ESTIMATING UNCERTAINTY

Approach

- ✦ Calculate error term of land area by management system in NRI (by MLRA)
- ✦ Estimate error term of C change rates for major management systems from long-term experiment data
- ✦ Monte-Carlo analysis combining error estimates for land areas and rates to generate mean and distribution of C stock changes

Conclusions

- ❖ Our IPCC-based (1990) estimate is that mineral soils are sequestering about 14 MMT of C per year as a result of changes in land use and land management.
- ❖ Cultivated organic soils are a net source estimated at 6 MMT of C per year.
- ❖ Further evaluation of the IPCC method and implementation of a dynamic simulation based estimate are in progress.
- ❖ Future work will include incorporating the 1997 NRI data, analyzing projected scenarios, and uncertainty analysis.

Steven Hamburg Presentation – March 28, 2000

Issues for Operationalizing Articles 3.3 and 3.4 (as it relates to forestry) of Kyoto Protocol

Key Assumptions/Issues

a) Is symmetrical carbon accounting desirable?

If goal of the UNFCCC is to reduce the rate of growth of atmospheric concentrations of greenhouse gases, then the answer is yes.

b) Should carbon credits for sequestration be awarded conservatively?

If the net goal of the Kyoto Protocol is to reduce greenhouse gas emissions then the answer is yes.

c) Is full carbon accounting necessary if carbon credits are awarded conservatively?

If carbon sequestration is to be an economically viable mitigation tool than full C accounting should not be considered a goal unto itself.

Definitions of a Forest

- **Why is the definition of a forest key to implementing Article of 3.3 of the Kyoto Protocol?**
What is and is not a forest largely defines ARD.
- **What should be the basis for the definition of what is a forest?**

Vegetation characteristics

- Assessment of forest / non-forest based on objective, measurable criteria.
Methods include cover, carbon content, and potential vegetation

Land-use or administrative characteristics

- Compatible with some countries' methods for identifying forests.
- Land-use designation would not necessarily reflect actual C stocks on the land.
- A change in land-use designation will create ARD land, but that may or may not be associated with a change in C stocks.

- **Should the criterion that distinguishes forest from non-forest vary by biome, by country, or be the same for all Annex I countries?**

Vary by biome

- Threshold values must be determined for major vegetation types and/or ecosystems.
- Differences in vegetation types are taken into account.
- More compatible with national vegetation surveys.

Vary by country

- One threshold value chosen by each country, thus allowing the use of existing data.
- Some vegetation types and land uses that would be regarded as forest in some countries may be classified as non-forest in others.

Same for all Annex 1 countries

- A universal threshold would be applied for all ecosystem types and climatic zones.
- Does not take into account the differences between ecosystems and climatic zones.

How could Afforestation, Reforestation and Deforestation be defined?

- **Should the definition of “reforestation” include or exclude the reestablishment of tree cover after clear-cut harvesting?**

Include

- The area of ARD land will be large, as areas will be added as they undergo a harvest-regeneration cycle.
- Will result in unbalanced accounting at the stand and landscape levels if harvesting is not considered deforestation: actual C stock changes will not match reported changes in the first commitment period and maybe beyond

Exclude

- Relatively small areas of most Annex I countries will become ARD land.
- There will be balanced accounting at the stand and landscape levels.

- **Should (re)establishment of forests through natural means be considered afforestation or reforestation?**

Yes

- Allows for consideration of natural regeneration, which accounts for 60% of all areas restocked in Annex I countries (82% when regeneration enhanced by planting is included; the rest is planting).
- Result in more ARD area compared to the “No” option.
- May encourage natural regeneration methods that lead to improved biodiversity.

No

- Restricts afforestation and reforestation to only planting activities.
- Problems in distinguishing direct human-induced reforestation / afforestation are reduced because any planting or seeding activity is likely to be called direct human induced.
- Results in less ARD area compared to the “Yes” option.

Defining Afforestation, Reforestation and deforestation (ARD)

- **Afforestation – non-forest to forest after a long period without forest**
How long since there was a forest on the site?
Was there ever a forest on the site?
- **Reforestation – non-forest to forest after a shorter period of time with out forest**
How long since there was a forest on the site?
What is causing forest regrowth?
- **Deforestation – converting forest to non-forest**

Established definitions of ARD

- **FAO**

- | | |
|---------------|--|
| Forest | <ul style="list-style-type: none">• Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity in situ. May consist <u>either</u> of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; <u>or</u> open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest. |
| Deforestation | <ul style="list-style-type: none">• Refers to change of land cover with depletion of tree crown cover to less than 10 percent. |
| Afforestation | <ul style="list-style-type: none">• Artificial establishment of forest on lands which previously did not carry forest within living memory. |

- **IPCC**

- | | |
|---------------|--|
| Forest | <ul style="list-style-type: none">• Within the guidelines there exists no specific definition of forest, but rather that is left to the discretion of the reporting countries. |
| Deforestation | <ul style="list-style-type: none">• Conversion of forest to non-forest.• Note: No definition provided in the Glossary. |
| Afforestation | <ul style="list-style-type: none">• IPCC Guidelines Glossary: Planting of new forests on lands which, historically, have not contained forests. |
| Reforestation | <ul style="list-style-type: none">• IPCC Guidelines Glossary: Planting of forests on lands which have, historically, previously contained forests but which have been converted to some other use. |

- **Alternative definitions**

- Forest
- a). Area being managed/designated as a forest
 - b). Area of land $> Y\%$ of cover of woody vegetation of $> Z$ m height
 - c). Area of land that has $X \text{ tC ha}^{-1}$
 - d). Would contain V attribute at maturity
 - e). Any of the above attributes defined by region, biome or country
- Deforestation
 - a). Conversion of forest to non-forest
 - b). Decrease in potential crown cover of $W\%$
 - Afforestation
 - a). Activities that lead to the conversion of non-forest to forest ($> Z$ years since it was a forest)
 - b). Conversion of non-forest to forest ($> Z$ years since it was a forest)
 - Reforestation
 - a). Activities that lead to the conversion of non-forest to forest ($< Z$ years since it was a forest)
 - b). Conversion of non-forest to forest ($< Z$ years since it was a forest)
 - c). Increase in potential crown cover of $W\%$

Practical considerations:

- **Can “direct human induced” be separated from non-human induced carbon stock changes?**
- In limited situations differentiation is possible e.g. large remote fires
- Differentiation will greatly increase the necessary monitoring and accounting
- Differentiation will increase uncertainty associated with monitoring and greatly complicate verification
- Differentiation will increase monitoring and verification costs
- Most types of indirect influence only separable theoretically , not empirically (e.g. CO_2 or N fertilization)

- **Should the qualifier “direct human induced” refer only to the ARD activities, or also to the stock changes resulting from these ARD activities?**

Refer only to ARD activities

- All stock changes on ARD land are accounted.
- Easier to implement.

Refer to ARD activities and to the resultant stock changes

- Only a part of the stock changes on ARD land are accounted for.
- Changes in stocks are very difficult to attribute to direct human-induced activities vs. indirect or natural effects (e.g., CO₂-fertilization, N-deposition).
- Large uncertainty associated with stock changes, and great difficulty verifying them, as estimates would heavily rely on the use of models.
- Net-net approach for ARD activities that are a forest / non-forest transition.
- Gross-net approach (emissions and removals counted in the commitment period but not compared against those in 1990) for all other ARD activities like regeneration after harvest.
- Compatible with some countries' methods for identifying forests.
- If based on actual vegetation characteristics, then the land status after clear-cut harvest is always non-forest. If potential vegetation characteristics are used, then land status after clear-cut harvest is forest if the vegetation is expected to return above the threshold.

- *Should a maximum spatial assessment unit be specified?*
- If the spatial assessment unit is relatively large then ARD activities affecting areas within the assessment unit may not be registered (e.g., deforestation of 89 ha within an assessment unit of 100 ha, using a crown cover threshold of 10%).
- Monitoring costs would be low if the unit is large.
- If the spatial assessment unit is relatively small then most ARD activities will be captured.
- Monitoring costs could be high if the maximum unit is small.

- **Should all future C stock changes on ARD lands be counted?**

Yes

- Assessment of stock changes would be easier to implement
- Stock changes associated with natural events on ARD land would be counted

No

- Reduced reported stock changes
- Could result in mis-match between real and reported stock changes

- **Should forest management be included under Article 3.4?**

Yes

- Would increase the amount of land considered
- Could encourage more C conservative forest management techniques

No

- Higher monitoring costs
- Higher uncertainty associated with measuring small changes in C stocks over large areas of land
- If only C stock changes associated with activities taking place since 1990 it would take 60-100 years before a positive net carbon sequestration rate would occur
- There is no soil monitoring system in place that could effectively monitor changes in soil carbon associated with a wide range of forestry practices. Soils would both gain and lose carbon depending on the activity, climate and soil type.

**Agricultural Soils:
How Can They Contribute to
Greenhouse Gas Reductions?**

Bruce A. Babcock
Center for Agricultural and Rural
Development
Iowa State University

Overview

- Actions agriculture can take to sequester carbon in soil
 - Potential carbon sequestered
(Lal, Kimble, Follett, and Cole)
 - Definition of actions for inclusion in international treaties
- Economics of soil carbon sequestration
 - Institutional structure to obtain soil carbon
 - Is it worth fighting for?
- Impacts of full accounting

Actions that Sequester Carbon: Cropping Practices

- Less intensive tillage
- Increased (better) use of manure and other organic materials
- Increase biomass production
 - More irrigation
 - Improved soil water management
 - Fertilizer use
 - Variety selection

Actions that Sequester Carbon: Land Use Changes

- Plant winter cover crops
- Reduce fallow land
- Convert intensively tilled land to grassland or woodland
- Restore degraded land
 - Saline land
 - Abandoned mines
 - Highly eroded land

Tillage and Residue Management: *How does it build carbon?*

- Reduces release of existing soil carbon
- Greater proportion of after-harvest plant residue goes to soil
- Reduction in soil erosion

Tillage and Residue Management: *Definition and amount sequestered*

Conservation tillage: > 30% of previous crop's residue remains after planting

- Mulch till
- Ridge till
- No-till
- Reduced tillage - 15 to 30%
- Conventional tillage: < 15%

Potential sequestered: 35 - 107 mmt/yr

Addition of manure and other organic material

How does it build carbon?

- Switch from anaerobic lagoons reduce methane production
- Switch from burning reduces emissions
- Non-intensive tillage needed for soil incorporation

Addition of manure and other organic material

Definition and amount sequestered

- Replace anaerobic lagoons with dry or slurry manure management system
- Reduced burning of agricultural residues
- Apply other biosolids to agricultural lands

Potential sequestered: 3 - 9 mmt/yr

Increased biomass production

How does it build carbon?

- Greater amount of plant material increases potential carbon sequestration

Increased biomass production

Definition and amount sequestered

- Look at crop yields as a measure of biomass production
- New crop varieties may change the ratio of total biomass to crop yields

Potential sequestered: 11 - 30 mmt/yr

Plant Winter Cover Crops and Reduce Fallow Land

How does it build carbon?

- Greater amount of plant material increases potential carbon sequestration
- Decreases soil erosion
- Decreases decomposition rates of residue in soil

Plant Winter Cover Crops and Reduce Fallow Land

Definition and amount sequestered

- Lack of bare soil during the winter or during the growing season.

Potential sequestered: 6 - 18 mmt/yr

Convert Intensively Tilled Land

How does it build carbon?

- Reduce soil carbon loss from tillage
- Increase actual soil carbon levels through the growing of grass and woody shrubs.

Convert Intensively Tilled Land

Definition and amount sequestered

- Total cropland taken out of production and enrolled in government programs, or enrolled in carbon sequestration project.

Potential sequestered: 6 - 13 mmt/yr

Restore Degraded Lands

How does it build carbon?

- Land with non-fertile soils can accept large amounts of organic material
- Biomass production on saline lands can be increased dramatically by variety selection and soil management

Restore Degraded Lands

Definition and amount sequestered

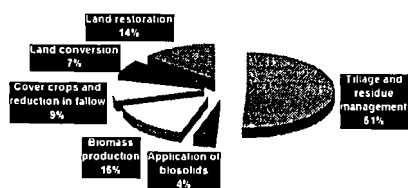
- Project-specific definition due to ability to locate the degraded land.

Potential sequestered: 11 - 25 mmt/yr

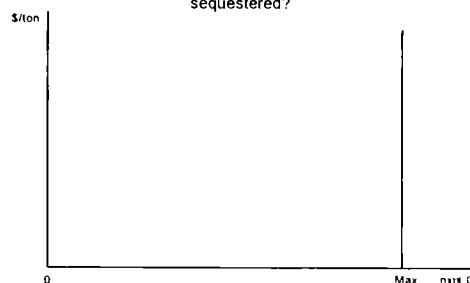
Potential Sources and Amounts of Soil Carbon Sequestration

	million metric tons per year	
	Low	High
Tillage and residue management	35	107
Application of biosolids	3	9
Biomass production	11	30
Cover crops and reduction in fallow	6	18
Land conversion	6	13
Land restoration	11	25
Total	72	202

Where is the Carbon Potential?



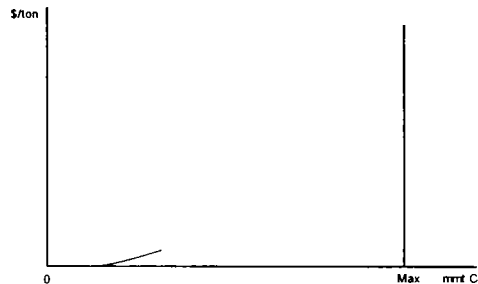
What proportion of potential soil carbon will be sequestered?



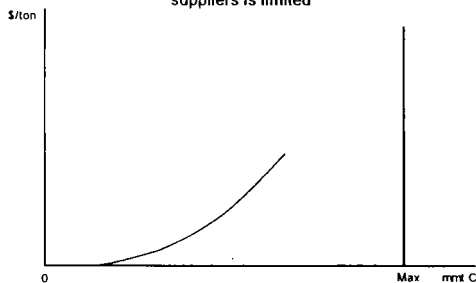
Initial amounts of carbon may be obtained easily

- After all many of the actions needed to sequester carbon are already being done:
 - Conservation tillage
 - Irrigation
 - Land application of manure
 - Intensive fertilization
 - Continuous cropping and winter cover crops

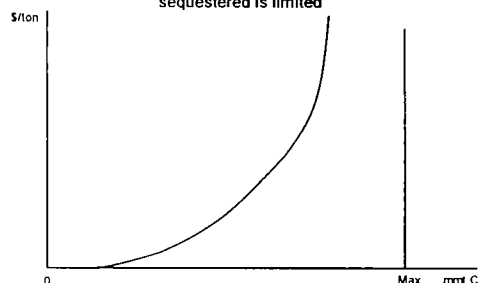
There will be some very low-cost suppliers of carbon



But the number of "on the edge" or indifferent suppliers is limited



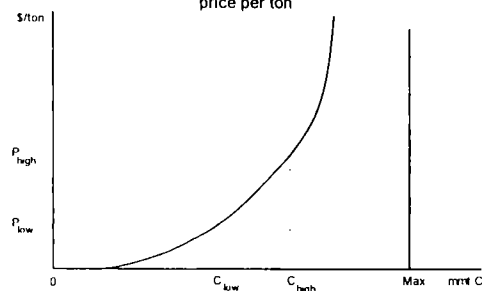
And the total amount of carbon that can be sequestered is limited



What proportion of carbon is economically feasible?

- Depends on the market price of carbon
- Higher the price, the greater the proportion

Proportion that can be sequestered depends on the price per ton



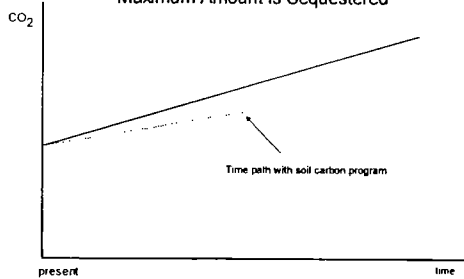
Potential Obstacles to Sequestering Carbon in U.S. Soils

- Supply of sequestered carbon temporary
- Uncertainty about site-specific supply of sequestered carbon is large
- Implementation and verification of action difficult due to non-point source of supplies

Most Soil Carbon Actions are Temporary

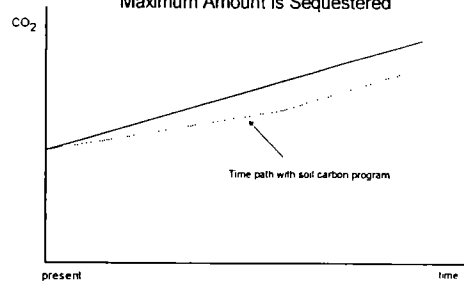
- Soils can only hold so much carbon
 - Over time the net additional amount sequestered will be zero
- Stored carbon can easily be lost through intensive tillage

Benefit of Soil Carbon Sequestration When Maximum Amount is Sequestered



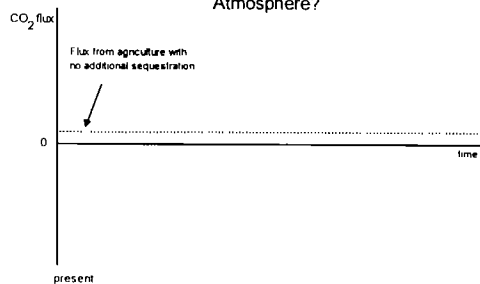
Time path with soil carbon program

Benefit of Soil Carbon Sequestration When Maximum Amount is Sequestered

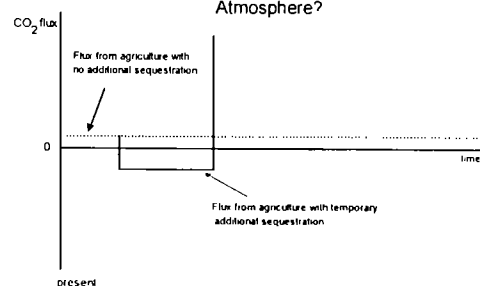


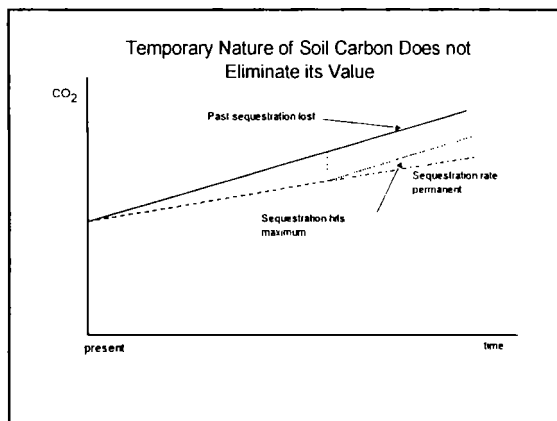
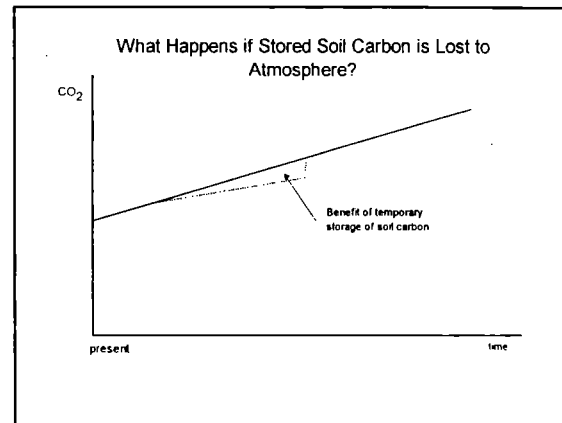
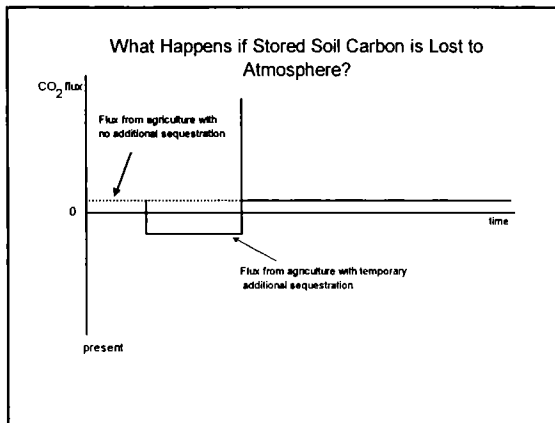
Time path with soil carbon program

What Happens if Stored Soil Carbon is Lost to Atmosphere?



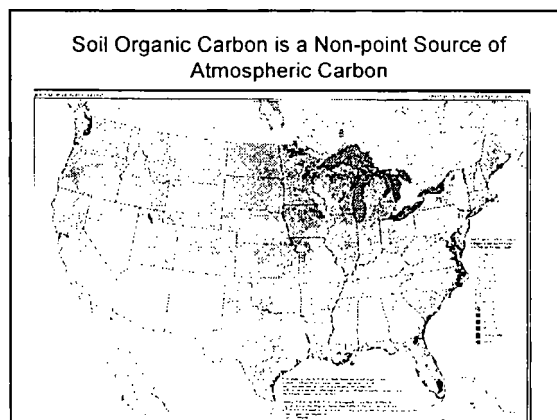
What Happens if Stored Soil Carbon is Lost to Atmosphere?





How to Overcome Nonpoint Source of Supplies?

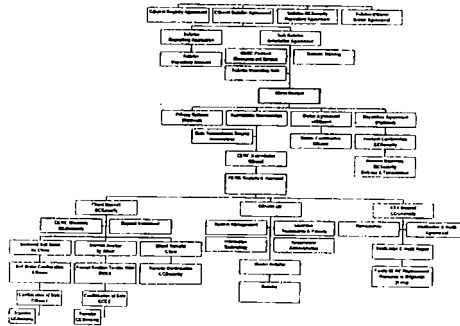
- An individual farmer sequesters relatively little carbon.
- The farmer will need a consolidator to combine credits from many farmers and then make a sell.
- The buyer will need assurance that each farmer is actually sequestering the carbon.



Does the government have to be the consolidator for agriculture?

- Private sector (C-Quest and others) is already putting such a system into place.
- System includes a third part guarantor who is paid in carbon credits and who compensates unfilled contracts with "bank" of carbon credits.
- Price of credits will be determined by their quality.

C-Quest's System of Obtaining Non-point Carbon Credits



Use of consolidators facilitates carbon trading

- Consolidator working with broker presents a quantity of carbon credits that are guaranteed by a third party to buyers.
- Buyers are generally point source emitters.
- This plan approaches point source trading.

Is verification too costly?

- Cost of action verification depends on:
 1. "Observability" of action
 2. Existence of complementary field staff (such as crop insurance agents and claims adjusters or field agronomist staff).

Which actions are observable?

- Conservation tillage
- Change in crop mix including winter cover crops
- Actions that are verified to ensure compliance with government programs such as CRP and buffer strips.
- Land restoration
- New irrigation system

Which actions are unobservable?

- Actions taken to increase crop yield such as improved fertility management or variety selection.
- Difficult to verify utilization of organic soil amendments.

Impacts of Full-Cost Accounting

- Conservation tillage would get additional credits for saving in fuel use but slight reduction due to increased herbicide use. (How greenhouse gas friendly is Roundup?)
- Conservation tillage would also get additional credits for reduction in soil erosion.

Impacts of Full-Cost Accounting

- Winter cover crops and reduced fallow would get credit for reduction in soil erosion, but lose some for fuel use and nitrogen fertilizer use.
- Land conversion would get additional credits for reduction in fuel, chemical, and fertilizer use.

Additionality: Some issues

- At the sector or macro level, fairly easy to document changes in adoption of practices relative to a baseline:
 - Conservation tillage
 - Crop yields
 - Land use
 - Even total fuel, fertilizer, and chemical use.

Additionality at the macro level

- And resulting sectoral estimates of change in soil carbon levels are fairly reliable.
- Models may be right on average.
- Apply to a large number of sites, then aggregate estimate will not be too far off.

Some problems at the micro or site-specific level

- More difficult to assess whether a particular farm would be doing a practice anyway.
- Definition of actions critical in estimating the baseline.

Example: Should a no-till farmer be paid for maintaining practice?

- Many no-till farmers find that they "need" to use tillage every five or seven years.
- But this tillage can result in a loss of built-up carbon.
- If the baseline recognizes this practice then no-till farmers will be given a large amount of credit for refraining from tilling every seventh year.

Reliability of models a problem at micro level

- Difficult to estimate the soil carbon change at a particular site given a change in practice.
- Can it be "proven" that the credited change actually occurs on that site?
- Problem is reduced if many farmers are lumped together by consolidators.

*Land Use, Land-use Change and Forestry Projects
and
the Kyoto Mechanisms*

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Senior Scientist
Lawrence Berkeley National Laboratory
Berkeley, CA USA

28 March 2000



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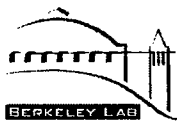
Key Concerns about LULUCF Projects

- Can baselines be set that are credible? What are the alternative approaches ?
- How should project additionality be determined? What tests are appropriate?
- How long should carbon stocks of a LULUCF project be maintained?
- Can project leakage be controlled?
- How well can carbon stocks of LULUCF projects be monitored?
- Are developing country concerns about LULUCF real? Can these be alleviated?
- How might a private developers' perspective affect the potential for CDM/JI projects?

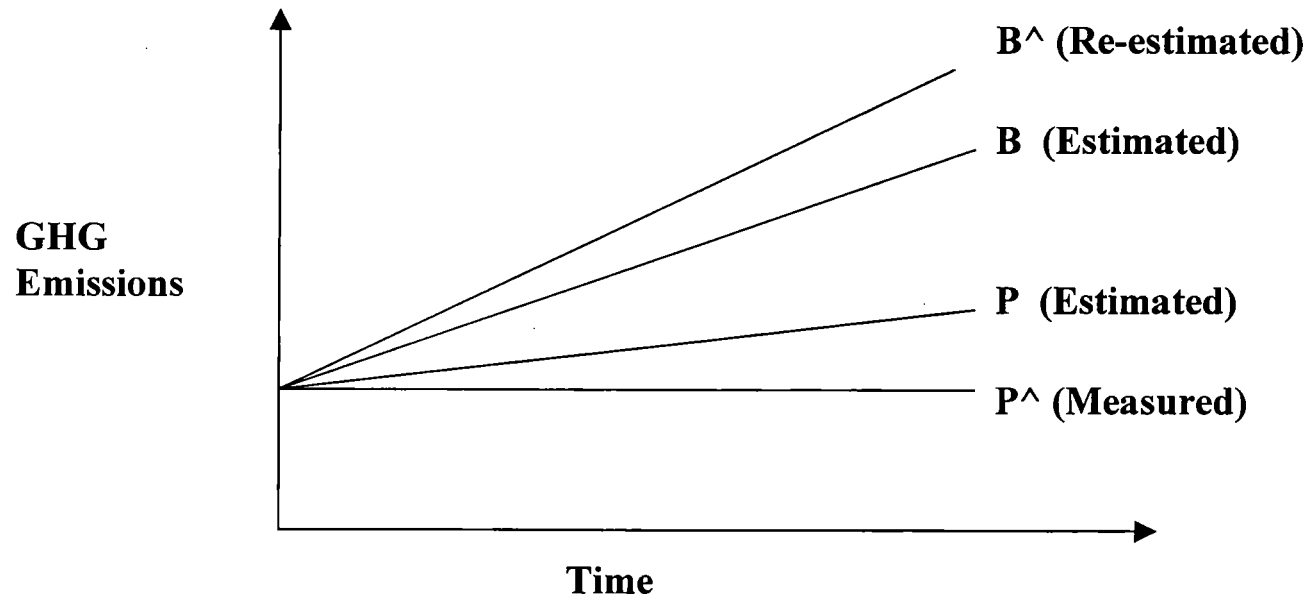


Baselines

- Fixed or adjustable baselines
 - Fixed baseline would reduce uncertainty
 - Adjustable baselines would ensure more realistic offsets, but would increase cost and uncertainty
 - Periodic adjustments may be one solution
- Project-specific vs. Generic
 - Project baselines may be set strategically to maximize credits
 - Generic baselines may reduce transaction costs, be transparent, and provide consistency across projects; but are yet to be tested
 - Setting minimum performance benchmarks would avoid rewarding projects with poor practices

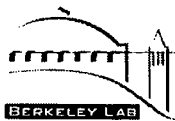


Conceptual Framework



$P - B$: Estimated net (additional) GHG savings

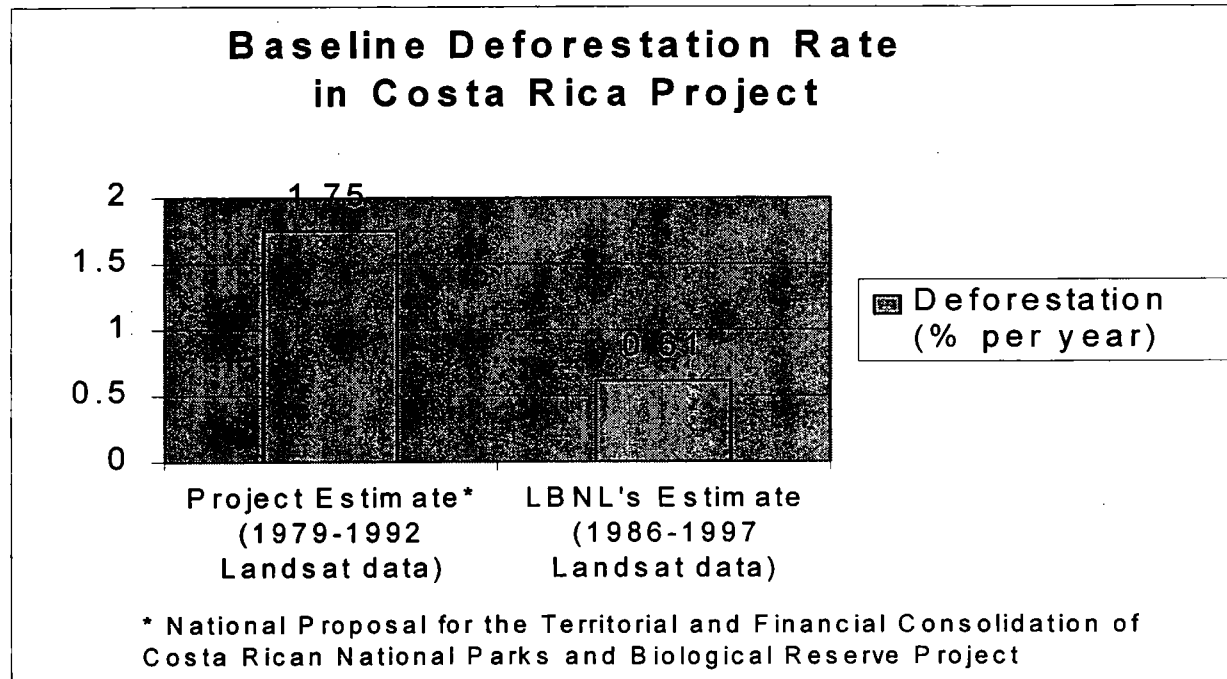
$P^ - B^$: Calculated net (additional) GHG savings
(after monitoring and evaluation of energy use)



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Baselines Can Change with New Data



- PAP project estimated a baseline of 15.7 Mt C stock
- LBNL estimated a baseline of 8.7 Mt using the 1986-97 data set

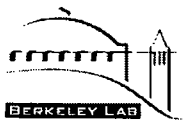


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Three Tests May be Used to Check Environmental Additionality of a Project

- Need to determine that the estimated GHG benefits of a project are truly additional (environmental additionality)
- Tests for additionality:
 - Technological test -- Project activities result in the introduction of new technologies and/or practices, or the removal of barriers
 - Institutional test -- Project activities go beyond the scope of ongoing policies/programs of institutions or governments
 - Financial test -- Project incurs higher costs or risks compared with baseline activities



Three Approaches May be Used to Address Concerns About Project Permanence

- Project runs in perpetuity -- Project carbon stock is locked in forever
 - If the carbon stock is released for any reason, solutions include
 - » Replace it with a new project
 - » Claim partial credit to begin with
 - » Create buffer zones at the start of the project
- Project carbon stock is assumed to be released at the end of the project and the amount is debited in the year of release
- Ton-year approach arbitrarily assumes that atmospheric carbon lasts 100 years
 - The assumption results in an imputed value for delayed carbon emissions from forestry projects



Leakage

- Leakage can be due to shifting of activities and/or market effects
- Providing socioeconomic benefits to project dwellers can reduce or eliminate leakage due to activity shifting
- Monitoring of activities within and outside project boundaries can help track leakage. Observed leakage may be offset through
 - Buffer zones as in the PAP project in Costa Rica
 - Reducing the estimated carbon benefits as in the Reduced Impact Logging (RIL) Project in Malaysia.
- Standard coefficients calibrated for different project types may be used to estimate leakage effects.



Measuring Changes in Carbon Stocks of Forestry Projects Can Be Just as Reliable as that of Emissions from Energy Projects

- Carbon pools -- Live and dead biomass, soil, and wood products
- In actual practice, projects have focused primarily on live biomass and in decreasing order on the other pools
- Reliable technical approaches exist to measure each pool, but monitoring across an extensive domain is difficult and complex
- Monitoring power plant emissions avoided by energy mitigation options is just as challenging
- Reliable technical approaches exist, but implementation is expensive or implausible across institutional boundaries



Evaluation of AIJ and AIJ-Like Projects Shows that Developing Country Concerns Are Being Addressed

- A 1998 LBNL study of 12 ongoing and potential jointly implemented (AIJ) energy and forestry projects/programs in Brazil, India, Mexico, and South Africa revealed that projects would
 - provide wood products and timber for export and generate rural employment
 - provide watershed management, control soil erosion, and improve biodiversity
 - transfer higher yielding plant species and new technology
- Capacity to estimate, monitor, evaluate, and verify carbon stocks remained a concern



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Private Developers' Perspective May Favor Forestry over Energy CDM/JI Projects

- If CDM/JI is to be implemented primarily by private companies, a developers' financial perspective is important
- Debiting carbon at project completion has little impact on a project's net present value due to high (>15%) discount rates
- Revising baselines and controlling leakage will add to project cost, but not significantly more than for energy
- Evaluation of Brazil projects shows that carbon revenue from a forestry project is a much larger proportion of total revenue than for energy projects
 - Incentive to establish projects to save carbon is higher in forestry than in the energy sector



Kyoto Protocol Excerpts

Articles 3, 6, & 12

Annexes A & B

- (viii) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy;

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency and effectiveness. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

2. The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

3. The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as to minimize adverse effects, including the adverse effects of climate change, effects on international trade, and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol, if it decides that it would be beneficial to coordinate any of the policies and measures in paragraph 1(a) above, taking into account different national circumstances and potential effects, shall consider ways and means to elaborate the coordination of such policies and measures.

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

2. Each Party included in Annex I shall, by 2005, have made demonstrable progress in achieving its commitments under this Protocol.

3. The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

4. Prior to the first session of the Conference of the Parties serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the Subsidiary Body for Scientific and Technological Advice, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent years. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable thereafter, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the Intergovernmental Panel on Climate Change, the advice provided by the Subsidiary Body for Scientific and Technological Advice in accordance with Article 5 and the decisions of the Conference of the Parties. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

5. The Parties included in Annex I undergoing the process of transition to a market economy whose base year or period was established pursuant to decision 9/CP.2 of the Conference of the Parties at its second session shall use that base year or period for the implementation of their commitments under this Article. Any other Party included in Annex I undergoing the process of transition to a market economy which has not yet submitted its first national communication under Article 12 of the Convention may also notify the Conference of the Parties serving as the meeting of the Parties to this Protocol that it intends to use an historical base year or period other than 1990 for the implementation of its commitments under this Article. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall decide on the acceptance of such notification.

6. Taking into account Article 4, paragraph 6, of the Convention, in the implementation of their commitments under this Protocol other than those under this Article, a certain degree of flexibility shall be allowed by the Conference of the Parties serving as the meeting of the Parties to this Protocol to the Parties included in Annex I undergoing the process of transition to a market economy.

7. In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land-use change and forestry constituted a net source of greenhouse gas emissions in 1990 shall include in their 1990 emissions base year or period the aggregate anthropogenic carbon dioxide equivalent emissions by sources minus removals by sinks in 1990 from land-use change for the purposes of calculating their assigned amount.

8. Any Party included in Annex I may use 1995 as its base year for hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for the purposes of the calculation referred to in paragraph 7 above.

9. Commitments for subsequent periods for Parties included in Annex I shall be established in amendments to Annex B to this Protocol, which shall be adopted in accordance with the provisions of Article 21, paragraph 7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall initiate the consideration of such commitments at least seven years before the end of the first commitment period referred to in paragraph 1 above.

10. Any emission reduction units, or any part of an assigned amount, which a Party acquires from another Party in accordance with the provisions of Article 6 or of Article 17 shall be added to the assigned amount for the acquiring Party.

11. Any emission reduction units, or any part of an assigned amount, which a Party transfers to another Party in accordance with the provisions of Article 6 or of Article 17 shall be subtracted from the assigned amount for the transferring Party.

12. Any certified emission reductions which a Party acquires from another Party in accordance with the provisions of Article 12 shall be added to the assigned amount for the acquiring Party.

13. If the emissions of a Party included in Annex I in a commitment period are less than its assigned amount under this Article, this difference shall, on request of that Party, be added to the assigned amount for that Party for subsequent commitment periods.

14. Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention. In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on Parties referred

to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

Article 4

1. Any Parties included in Annex I that have reached an agreement to fulfil their commitments under Article 3 jointly, shall be deemed to have met those commitments provided that their total combined aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of Article 3. The respective emission level allocated to each of the Parties to the agreement shall be set out in that agreement.
2. The Parties to any such agreement shall notify the secretariat of the terms of the agreement on the date of deposit of their instruments of ratification, acceptance or approval of this Protocol, or accession thereto. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of the agreement.
3. Any such agreement shall remain in operation for the duration of the commitment period specified in Article 3, paragraph 7.
4. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization, any alteration in the composition of the organization after adoption of this Protocol shall not affect existing commitments under this Protocol. Any alteration in the composition of the organization shall only apply for the purposes of those commitments under Article 3 that are adopted subsequent to that alteration.
5. In the event of failure by the Parties to such an agreement to achieve their total combined level of emission reductions, each Party to that agreement shall be responsible for its own level of emissions set out in the agreement.
6. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Protocol, each member State of that regional economic integration organization individually, and together with the regional economic integration organization acting in accordance with Article 24, shall, in the event of failure to achieve the total combined level of emission reductions, be responsible for its level of emissions as notified in accordance with this Article.

Article 5

1. Each Party included in Annex I shall have in place, no later than one year prior to the start of the first commitment period, a national system for the estimation of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol. Guidelines for such national systems, which shall incorporate the

methodologies specified in paragraph 2 below, shall be decided upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session.

2. Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Protocol at its first session. Based on the work of, *inter alia*, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

3. The global warming potentials used to calculate the carbon dioxide equivalence of anthropogenic emissions by sources and removals by sinks of greenhouse gases listed in Annex A shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Based on the work of, *inter alia*, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Scientific and Technological Advice, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall regularly review and, as appropriate, revise the global warming potential of each such greenhouse gas, taking fully into account any relevant decisions by the Conference of the Parties. Any revision to a global warming potential shall apply only to commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6

1. For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

- (a) Any such project has the approval of the Parties involved;
- (b) Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur;
- (c) It does not acquire any emission reduction units if it is not in compliance with its obligations under Articles 5 and 7; and

(d) The acquisition of emission reduction units shall be supplemental to domestic actions for the purposes of meeting commitments under Article 3.

2. The Conference of the Parties serving as the meeting of the Parties to this Protocol may, at its first session or as soon as practicable thereafter, further elaborate guidelines for the implementation of this Article, including for verification and reporting.

3. A Party included in Annex I may authorize legal entities to participate, under its responsibility, in actions leading to the generation, transfer or acquisition under this Article of emission reduction units.

4. If a question of implementation by a Party included in Annex I of the requirements referred to in this Article is identified in accordance with the relevant provisions of Article 8, transfers and acquisitions of emission reduction units may continue to be made after the question has been identified, provided that any such units may not be used by a Party to meet its commitments under Article 3 until any issue of compliance is resolved.

Article 7

1. Each Party included in Annex I shall incorporate in its annual inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol, submitted in accordance with the relevant decisions of the Conference of the Parties, the necessary supplementary information for the purposes of ensuring compliance with Article 3, to be determined in accordance with paragraph 4 below.

2. Each Party included in Annex I shall incorporate in its national communication, submitted under Article 12 of the Convention, the supplementary information necessary to demonstrate compliance with its commitments under this Protocol, to be determined in accordance with paragraph 4 below.

3. Each Party included in Annex I shall submit the information required under paragraph 1 above annually, beginning with the first inventory due under the Convention for the first year of the commitment period after this Protocol has entered into force for that Party. Each such Party shall submit the information required under paragraph 2 above as part of the first national communication due under the Convention after this Protocol has entered into force for it and after the adoption of guidelines as provided for in paragraph 4 below. The frequency of subsequent submission of information required under this Article shall be determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol, taking into account any timetable for the submission of national communications decided upon by the Conference of the Parties.

4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall adopt at its first session, and review periodically thereafter, guidelines for the preparation of the information required under this Article, taking into account guidelines for the preparation of

Article 11

1. In the implementation of Article 10, Parties shall take into account the provisions of Article 4, paragraphs 4, 5, 7, 8 and 9, of the Convention.
2. In the context of the implementation of Article 4, paragraph 1, of the Convention, in accordance with the provisions of Article 4, paragraph 3, and Article 11 of the Convention, and through the entity or entities entrusted with the operation of the financial mechanism of the Convention, the developed country Parties and other developed Parties included in Annex II to the Convention shall:

- (a) Provide new and additional financial resources to meet the agreed full costs incurred by developing country Parties in advancing the implementation of existing commitments under Article 4, paragraph 1(a), of the Convention that are covered in Article 10, subparagraph (a); and

- (b) Also provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of advancing the implementation of existing commitments under Article 4, paragraph 1, of the Convention that are covered by Article 10 and that are agreed between a developing country Party and the international entity or entities referred to in Article 11 of the Convention, in accordance with that Article.

The implementation of these existing commitments shall take into account the need for adequacy and predictability in the flow of funds and the importance of appropriate burden sharing among developed country Parties. The guidance to the entity or entities entrusted with the operation of the financial mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before the adoption of this Protocol, shall apply *mutatis mutandis* to the provisions of this paragraph.

3. The developed country Parties and other developed Parties in Annex II to the Convention may also provide, and developing country Parties avail themselves of, financial resources for the implementation of Article 10, through bilateral, regional and other multilateral channels.

Article 12

1. A clean development mechanism is hereby defined.
2. The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

3. Under the clean development mechanism:
 - (a) Parties not included in Annex I will benefit from project activities resulting in certified emission reductions; and
 - (b) Parties included in Annex I may use the certified emission reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to this Protocol.
4. The clean development mechanism shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to this Protocol and be supervised by an executive board of the clean development mechanism.
5. Emission reductions resulting from each project activity shall be certified by operational entities to be designated by the Conference of the Parties serving as the meeting of the Parties to this Protocol, on the basis of:
 - (a) Voluntary participation approved by each Party involved;
 - (b) Real, measurable, and long-term benefits related to the mitigation of climate change; and
 - (c) Reductions in emissions that are additional to any that would occur in the absence of the certified project activity.
6. The clean development mechanism shall assist in arranging funding of certified project activities as necessary.
7. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, elaborate modalities and procedures with the objective of ensuring transparency, efficiency and accountability through independent auditing and verification of project activities.
8. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall ensure that a share of the proceeds from certified project activities is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.
9. Participation under the clean development mechanism, including in activities mentioned in paragraph 3(a) above and in the acquisition of certified emission reductions, may involve private and/or public entities, and is to be subject to whatever guidance may be provided by the executive board of the clean development mechanism.

10. Certified emission reductions obtained during the period from the year 2000 up to the beginning of the first commitment period can be used to assist in achieving compliance in the first commitment period.

Article 13

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Protocol.
2. Parties to the Convention that are not Parties to this Protocol may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Protocol. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, decisions under this Protocol shall be taken only by those that are Parties to this Protocol.
3. When the Conference of the Parties serves as the meeting of the Parties to this Protocol, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Protocol, shall be replaced by an additional member to be elected by and from amongst the Parties to this Protocol.
4. The Conference of the Parties serving as the meeting of the Parties to this Protocol shall keep under regular review the implementation of this Protocol and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Protocol and shall:
 - (a) Assess, on the basis of all information made available to it in accordance with the provisions of this Protocol, the implementation of this Protocol by the Parties, the overall effects of the measures taken pursuant to this Protocol, in particular environmental, economic and social effects as well as their cumulative impacts and the extent to which progress towards the objective of the Convention is being achieved;
 - (b) Periodically examine the obligations of the Parties under this Protocol, giving due consideration to any reviews required by Article 4, paragraph 2(d), and Article 7, paragraph 2, of the Convention, in the light of the objective of the Convention, the experience gained in its implementation and the evolution of scientific and technological knowledge, and in this respect consider and adopt regular reports on the implementation of this Protocol;
 - (c) Promote and facilitate the exchange of information on measures adopted by the Parties to address climate change and its effects, taking into account the differing circumstances, responsibilities and capabilities of the Parties and their respective commitments under this Protocol;
 - (d) Facilitate, at the request of two or more Parties, the coordination of measures adopted by them to address climate change and its effects, taking into account the differing

Annex A

Greenhouse gases

Carbon dioxide (CO₂)

Methane (CH₄)

Nitrous oxide (N₂O)

Hydrofluorocarbons (HFCs)

Perfluorocarbons (PFCs)

Sulphur hexafluoride (SF₆)

Sectors/source categories

Energy

Fuel combustion

Energy industries

Manufacturing industries and construction

Transport

Other sectors

Other

Fugitive emissions from fuels

Solid fuels

Oil and natural gas

Other

Industrial processes

Mineral products

Chemical industry

Metal production

Other production

Production of halocarbons and sulphur hexafluoride

Consumption of halocarbons and sulphur hexafluoride

Other

Solvent and other product use

Agriculture

Enteric fermentation

Manure management

Rice cultivation

Agricultural soils

Prescribed burning of savannas

Field burning of agricultural residues

Other

Waste

Solid waste disposal on land

Wastewater handling

Waste incineration

Other

Annex B

<u>Party</u>	<u>Quantified emission limitation or reduction commitment</u> (percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom of Great Britain and Northern Ireland	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy.

Summary for Policymakers

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1. *Introduction*

1. Under Article 3.1 of the Kyoto Protocol, the Annex I Parties have agreed to limit their emissions of greenhouse gases between 2008 and 2012.
2. The Kyoto Protocol recognizes that changes in greenhouse gas emissions by sources and removals by sinks resulting from land-use, land-use change and forestry activities may offer a range of options for assisting Parties to meet their quantified emission limitation and reduction commitments.
3. To implement the Kyoto Protocol, the Parties are likely to have to consider issues such as definitions, methodological issues, additional activities, activities eligible under Article 12, inventory guidelines, and how to address the issue of sustainable development:
 - Definitions, including: land-use, land-use change, forests, forestry activities, including afforestation, reforestation, deforestation, and carbon stocks.
 - Methodological Issues:
 - Rules for carbon stock accounting, including:
 - which carbon pools to include,
 - how to implement "since 1990," "direct human-induced," and "human-induced,"
 - how to address the effects of fires and pest outbreaks, baselines, permanence, leakage, and uncertainties, and
 - accuracy and precision in tracking carbon.
 - Approaches, such as geo-referencing and statistical sampling, associated with identifying "Kyoto Lands" and monitoring changes in carbon stocks
 - Verification procedures
 - Determination of how and which, if any, additional activities are included.
 - Whether land-use, land-use change and forestry activities are included in Article 12, and if so how, and which, if any.
 - What improvements, if any, are needed to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories.
 - What, if any, national and/or international environmental or sustainable development criteria should be associated with land use, land-use change and forestry activities and projects.
4. Therefore, to assist the Parties to the Protocol, both Annex-I, which have commitments, and non-Annex-I, this SPM provides relevant scientific and technical information in three Parts:
 - Part I describes how the global carbon cycle operates and the broad scale opportunities and implications of afforestation, reforestation, and deforestation (ARD) and additional human-induced activities, now and in the future.
 - Part II identifies likely decisions that Parties to the Protocol may have to make regarding definitions, and accounting rules. It identifies a range of options and discusses the implications and the inter-relationship among options.
 - Part III provides information that governments might find useful in making these decisions such as:
 - An assessment of models, ground-based and remotely-sensed measurements, and monitoring techniques for assessing changes in carbon stocks
 - The near- (first commitment period) and longer-term (50 year) potential of activities in Annex I and non-Annex I countries.
 - Issues of special significance to project-based activities
 - An evaluation of the applicability of Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories for national and project-level accounting
 - Implications of Article 3.3, 3.4 and project activities on sustainable development, i.e., socio-economic and environmental considerations

Part I

2. Global Carbon Overview

5. Terrestrial ecological systems, in which carbon is retained in live biomass, decomposing organic matter, and soil, play a crucial role in the global carbon cycle. Carbon is exchanged naturally between the biosphere and the atmosphere through photosynthesis, respiration, decomposition and combustion. Human activities change carbon stocks and fluxes between these pools and the atmosphere through land use, land-use change, and forestry (LULUCF) activities.
6. From 1800 to 1998 approximately 265 ± 20 Gt C has been emitted as carbon dioxide (CO_2) into the atmosphere from fossil fuel burning and cement production. About 140 ± 55 Gt C has been emitted as a result of land-use change, predominantly from forest ecosystems. This has led to an increase in the atmospheric abundance of carbon dioxide of 180 ± 10 Gt C (~ 30% per cent). The remainder, about 225 ± 60 Gt C, is estimated to have been sequestered in approximately equal amounts in the oceans and the terrestrial biosphere.[1.2.1]¹
7. During the 1980s, the net amount of carbon sequestered in terrestrial ecosystems was $0.2 (\pm 1.0)$ Gt C y^{-1} . This is the difference between a net emission of $2.0 (\pm 0.8)$ Gt C y^{-1} from land-use changes, primarily in the tropics, and a global terrestrial uptake of $2.2 (\pm 1.3)$ Gt C y^{-1} . In comparison, the annual emissions of carbon dioxide from fossil fuels during the same period was 6.3 Gt C y^{-1} . In the 1990s, the net amount of carbon sequestered in terrestrial ecosystems seems to have been larger (0.7 ± 1.0 Gt C y^{-1}), if we assume net emissions from land-use changes were similar to those of the 1980s, although the rate of the decadal increase is quite uncertain, on the order of $+0.5 \pm 1.6$ Gt C y^{-1} . This terrestrial sequestration results from land-use practices, the indirect effects of human activities (e.g. atmospheric CO_2 fertilization and nutrient deposition), and changing climate (both natural and anthropogenic). It is presently not possible to determine the relative importance of these different processes, which vary from region to region.[1.2.1]
8. Carbon is sequestered into both vegetation and soils in terrestrial ecosystems. Current carbon stocks are much larger in soils than in vegetation, particularly in non-forested ecosystems in middle and high latitudes. [1.2.1, Table 1 of this SPM]

Table 1: Global carbon stocks in vegetation and soil carbon pools down to a depth of 1 m.

Biome	Area (10 ⁹ ha)	Global Carbon Stocks (Gt C)		
		Vegetation	Soil	Total
Tropical forests	1.76	212	216	428
Temperate forests	1.04	59	100	159
Boreal forests	1.37	88	471	559
Tropical savannas	2.25	66	264	330
Temperate grasslands	1.25	9	295	304
Deserts & semi-deserts	4.55	8	191	199
Tundra	0.95	6	121	127
Wetlands	0.35	15	225	240
Croplands	1.60	3	128	131
Total	15.16	466	2011	2477

9. Commitments under the Kyoto Protocol require Annex I parties to reduce emissions by about 200 Mt C y^{-1} below 1990 levels and about 750 Mt C y^{-1} below business-as-usual projections based on the IPCC IS92a scenario. If current rates of afforestation, reforestation and deforestation are maintained from 1990 through to the first commitment period by Annex I countries, carbon stocks could increase by more than 100 Mt C y^{-1} . The potential impact of additional activities, if allowed, in Annex I countries during the first commitment period

¹ Numbers in brackets indicate relevant sections of the special report containing details.

- could exceed several hundred Mt C y⁻¹. A simple comparison suggests that the potential impact of Article 3.3 and 3.4 activities in Annex I countries alone could be comparable to the projected magnitude of reductions required by Annex I Parties. Such a comparison, however, risks under-estimating the difficulty in creating and implementing the incentives needed to achieve the potential. [see section 6.1 and 6.2 of this SPM for details]
10. In addition, there is potential for sequestering carbon into biomass, which is then stored over a time period of decades in wood products. Furthermore, biomass energy, based on waste by-products of wood/crops or from trees/crops grown expressly for this purpose, has the potential to lead to a significant reduction in net greenhouse gas emissions by substituting for fossil fuels. [1.4, 3/4]
11. Ecosystem models indicate that the additional terrestrial uptake of atmospheric carbon dioxide arising from the indirect effects of human activities (e.g., CO₂ fertilization and nutrient deposition) on a global scale is likely to be maintained for at least several decades in mature forest ecosystems, but may subsequently gradually diminish. One reason for this is that the capacity of some ecosystems to sequester additional carbon may be limited. Another reason is that the rate of photosynthesis will no longer increase as carbon dioxide concentration continues to rise, whereas respiration is expected to rise with increasing temperatures. A third reason is that tree mortality may result from climate change. Because of current uncertainties in our understanding with respect to acclimation of the physiological processes and climatic constraints and feedbacks amongst the processes, projections beyond a few decades are highly uncertain. However, forestry yield tables indicate that in new forests planted since 1990 in relation to Article 3.3, sequestration of carbon will continue for 20 to 50 years or more, especially in cooler climates, after establishment, depending on species and site conditions.[1.3.3]
12. Emissions of the greenhouse gases methane (CH₄) and nitrous oxide (N₂O) are also influenced by land-use activities. Global emissions have recently been estimated as 0.7 to 1.8 Gt Ceq y⁻¹ of CH₄ from livestock, rice paddies and wetlands (100 years IPCC GWP used to deduce carbon equivalents) and 0.5 to 1.8 Gt Ceq y⁻¹ of N₂O from agriculture and biomass burning. Global emissions of CH₄ and N₂O from land-use related activities exceed (when expressed as CO₂ equivalents) the net carbon dioxide emissions from land-use change. For some activities that result in changes in carbon stocks, changes in emissions of CH₄ and N₂O may significantly modify the net effect of the activities in terms of CO₂-eq emissions (e.g., restoration of wetlands, and fertilizer management of agricultural land).[1.2.2/3, 3.2.9]

Part II

3. Issues Associated with Definitions

13. For purposes of this Report in a given land area and time period, a full carbon accounting system would consist of a complete accounting for changes in carbon stocks across all carbon pools. Applying full carbon accounting to all land in each country would, in principle, yield the net carbon exchange between terrestrial ecosystems and the atmosphere. However, the Kyoto Protocol specifies, among other things, that attention be restricted to those land areas subject to "direct human-induced" (Article 3.3) or human-induced (Article 3.4) activities.
14. As used in this Report, a "symmetrical" accounting system for an area of land affected by an activity or project is one that, for all reported pools and over a specified period, accounts for all losses from, and all increases in, carbon stocks, i.e. it quantifies all emissions and/or removals, ensuring consistency with changes in atmospheric composition.
15. The term "Kyoto lands" is used as a term of convenience to denote lands that through the activities of afforestation, reforestation and deforestation (ARD) in Article 3.3, or through additional activities that might be approved under Article 3.4.

3.1. Forests, Afforestation, Reforestation, and Deforestation

16. Key to the identification of Kyoto lands under Article 3.3 is the definition of a forest coupled with definitions of afforestation, reforestation, and deforestation (ARD). The choice of definitions will determine how much land in Annex I countries is included under the provisions of Article 3.3. [2.2.2, 2.2.3, 3.2, 3.5.2, 3.5.3]
17. Countries have defined forests and other wooded lands, for a number of national and international purposes, in terms of (i) legal, administrative or cultural requirements; (ii) land use, (iii) canopy cover, or (iv) carbon density (essentially biomass density). Such definitions will not necessarily suffice for the particular needs of Articles 3.3 and 3.4. [2.2.2, 3.2]
18. Forest definitions based on legal, administrative or cultural considerations have limitations for carbon accounting as they may bear little relationship to the amount of carbon at a site. Definitions based on land-use alone can have similar limitations. [2.2.2, 3.2]
19. Most definitions of forest are based on a single threshold of minimum canopy cover. However, definitions based on a single threshold for canopy cover alone may allow changes in carbon stocks to remain unaccounted under Article 3.3. For example, if a high threshold for canopy cover (e.g. 70% canopy cover) is used in the definition of a forest, then many areas of sparse forest and woodland could be cleared without the losses in carbon being counted under Article 3.3 because the woody vegetation before clearing would not be defined as forest. If a low threshold is set (e.g., 10% canopy cover), then dense forest could be heavily degraded and significant amounts of carbon released, without the actions being designated as deforestation. This problem could be partly addressed by using national, regional or biome-specific thresholds, e.g., a low canopy cover for savannas and a high canopy cover for moist forests, or by definitions based on degradation or aggradation criteria. [2.2.2, 3.2, 3.3.2]
20. Definitions of forests based on carbon-density thresholds have similar issues with respect to thresholds as canopy cover-based definitions, but carbon-based thresholds are more closely linked to accounting requirements. [2.2.2]
21. Deforestation can be defined as the conversion of forest to non-forest. Reforestation and afforestation can be defined as the conversion of non-forested lands to forests. These definitions are consistent with the IPCC guidelines, and all three involve the concept of a land-use change. [2.2.3, 3.2]
22. An alternative definition of deforestation might be based on a decrease in the canopy cover or carbon density by a given amount. Similarly, afforestation and reforestation could be defined in terms of an increase in canopy cover or carbon density. None of these definitions involve the concept of a land-use change. [2.2.2, 3.2]
23. Definitions of a forest based strictly on actual canopy cover without consideration of potential canopy cover could lead to harvesting being referred to as deforestation and regeneration being referred to as reforestation thus creating large areas of Kyoto lands under Article 3.3. If the definition of a forest was based on the potential canopy cover at maturity with continuation of current land-use practices, harvesting/regeneration activities would not fall under Article 3.3. [2.2.2, 2.2.3, 3.2]
24. Some definitions of reforestation include the activity of regenerating trees immediately after disturbance or harvesting where no land-use change occurs. When such definitions of reforestation are used, but the accompanying definition of deforestation does not include disturbance or harvesting, asymmetric accounting can occur. Under such definitions of reforestation, many forestry management practices, e.g., the harvest-regeneration cycle, would create large areas of Kyoto lands. [2.2.3, 3.2, 3.5.2, 3.5.3]
25. There is no explicit reference in the Kyoto Protocol to forest harvesting. However, there are several consequences of using definitions that lead to the creation of Kyoto lands by the harvest-regeneration cycle. For example, a forest estate managed on a sustainable-yield basis where an area of forest is cut in a regular cycle (e.g., 1/50th of the forest is harvested and regenerated each year on a 50 year rotation cycle) may be in approximate carbon balance. However, only those stands harvested and regenerated since 1990 will be Kyoto

lands and the regrowth (carbon sink) on these lands will be less than the carbon emissions due to harvesting during commitment periods until all of the forest has become Kyoto land. If emissions from harvesting during a commitment period are counted, then during the first and possible subsequent commitment periods some parties could incur a net debit from a managed forest estate that is approximately in carbon balance. Alternately, if the accounting commences only with the act of regenerating forests so that emissions from harvesting and decaying slash are not counted even during the commitment period then Parties would receive a credit equivalent to the biomass growth during the commitment period in all forests harvested and regenerated since 1990. In this case, the forest estate managed on a sustained yield basis would generate carbon credits. In neither case would the estimated stock changes reflect the contribution of the system to atmospheric carbon dioxide. [3.2, 3.5.2]

26. Afforestation is usually defined as the establishment of forest on land that has been without forest for a period of time (e.g., 20-50 years or more) and was previously under a different land use. The precise period that distinguishes afforested from reforested land is not critical to defining lands covered under Article 3.3 provided afforestation and reforestation are treated identically in the Protocol, as they are in the IPCC guidelines. [2.2.3, 3.3.2]
27. For Kyoto lands created by deforestation between 1990 and the beginning of the first commitment period only a small-fraction of emissions (such as those from delayed carbon emissions from soil and wood products if they are accounted) will be debited. If these lands are subsequently reforested then there may be a carbon credit. This would lead to a discrepancy between the credit received and the carbon stock changes since 1990. Parties could avoid such an outcome if credit for reforestation is awarded only for the increment of carbon stocks above that on the land prior to deforestation or in 1990 or by specifying a minimum period during which the land has to have been non-forest prior to reforestation. Carbon stocks would need to be estimated for 1990, as already required by Article 3.4, or immediately before deforestation on all lands that are deforested post 1990. [3.3.2]
28. A discrepancy between the carbon stock changes since 1990 and the credit received can also occur when land is reforested or afforested between 1990 and 2008 but stocks are reduced either by harvesting or natural disturbance during a commitment period. Even though stocks may have increased since 1990, a significant debit could be recorded in a commitment period. This creates the possibility of a negative incentive for establishing new forests well in advance of the first commitment period, because any stock change prior to 2008 would not be credited but the later loss of this stock would be debited. If Parties wish to avoid this situation, carbon debits for activities which reduce carbon stocks on reforested or afforested lands could be limited to the net credits, if any, received in earlier commitment periods for carbon accumulating on this land. Such adjustments would not increase data requirements. [3.3.2]
29. There are definitional issues concerning the boundary between natural phenomena and direct human-induced activities, when, for example, significant forest losses occur as a result of natural or human-induced fires or disturbances such as pest outbreaks. It will be difficult to distinguish between natural and anthropogenic factors that influence the vulnerability of the land to disturbance. In cases involving non-Kyoto lands, where fires or pest outbreaks trigger land-use change, the consequences are similar to deforestation. If vegetation cover were allowed to recover, with no change in land use, such disturbances would not lead to a long-term change in carbon stocks. In the latter case, a question for policymakers is whether accounting should: (i) count neither the loss nor subsequent sequestration of carbon (symmetric accounting as is the case in the IPCC guidelines); (ii) count both the loss and subsequent sequestration of carbon (symmetric accounting, but will increase monitoring requirements); (iii) count only the loss of carbon (asymmetric accounting), or (iv) count only the subsequent sequestration (asymmetric accounting). [2.4.4, 2.2.3, 2.3.3]
30. In cases involving forested Kyoto lands where fires or pest outbreaks occur, a question for policymakers is whether accounting should: (i) count neither the loss or subsequent sequestration of carbon (symmetric accounting, but essentially changes the area burnt/defoliated to non-Kyoto land); (ii) count both the loss and subsequent sequestration of carbon (symmetric accounting); (iii) count only the loss of carbon (asymmetric accounting), or (iv) count only the subsequent sequestration (asymmetric accounting, and may create an incentive to burn forests).

31. Given the importance of the definitions of forests and ARD to the implementation of Article 3.3, seven illustrative definitional scenarios were developed for the Special Report that reflect a range of approaches that can be taken. These seven definitional scenarios, which are not intended to be exhaustive, highlight the complexity of combining definition elements and the possible implications of these combinations. [2.2.4, 3.2]

3.2. Additional Activities

32. Article 3.4 offers the option of including additional human-induced activities in the agricultural soils, land-use change and forestry categories for meeting national commitments. It therefore raises two questions: which activities will be added, if any, and how they will be added?

33. When inclusion of additional activities is considered, it is possible to interpret "activity" broadly, e.g., cropland management, or narrowly, e.g., change in tillage method, fertilization, or cover crops. Under either definitional interpretation, it is possible to choose a land-based or activity-based method of accounting for carbon impacts (see below). Those combined choices will have major impact on the accuracy, transparency, and verifiability of the reported amounts. The broad definition may lend itself more readily to land-based carbon stock change methods of measuring the net impact of the activity. The narrow interpretation of activity may lend itself to activity-based measures in some instances, where the area of practice reported is multiplied by research-derived estimates of changes in emissions or removals of greenhouse gases associated with the activity. The narrow definitions of additional activities may be useful if a small number of discrete activities are added under Article 3.4, whereas a broad interpretation can provide a more comprehensive framework for carbon accounting. [2.3.2, 4.3.2]

34. If the narrow definition of 'activity' is chosen in association with 'activity-based' accounting, it will be necessary to develop estimates of changes in carbon stocks/fluxes associated with each additional activity in each ecosystem type. Default values could be used but they are likely to introduce significant uncertainty that will be difficult to reduce without adopting research-developed rates for specific management regimes in particular environmental situations. This approach is feasible, but will take time and investment to develop. For broadly defined activities such as cropland, grazing land, or forest management, direct measures of stock changes, even where they involve significant effort and cost, may provide the most technically feasible approach to transparent and verifiable measurement of net carbon fluxes. [4.2.1, 4.3.2]

35. Some practices must be persistently maintained to retain the stored carbon stocks. Conservation tillage, for example, may significantly increase carbon stocks on cropland if carried on continuously, but where it is practiced for a time, then interrupted by a year of intensive tillage brought on by a weather situation or crop change, much of the previous multi-year gain in soil carbon can be lost. Measurements done on a stock-change basis, if done by a statistically-reliable periodic sampling process, should reflect the net effect of those gains and losses over a sampled area and give verifiable results. Activity-based estimates using annual practice application data (e.g., the total area of land under conservation tillage in a given year) may report results inconsistent with actual stock changes. [2.3.2]

4. Carbon Accounting

36. A well-designed carbon accounting system would provide transparent and verifiable recording and reporting of changes in carbon stocks or changes in greenhouse gas emissions by sources and removals by sinks from applicable land-use, land-use change and forestry activities and projects under Articles 3.3., 3.4, 3.7 and other relevant Articles. Such data would, in part, demonstrate compliance with the commitments defined by the Kyoto Protocol. [2.3.1]

37. A "land-based" approach to accounting would take as its starting point the total carbon stock in applicable carbon pools on land units subject to Kyoto activities. This involves first identifying land units on which applicable activities occur. Next, the total change in carbon stocks on these land units during the commitment

period is determined. Adjustments can then be made to reflect decisions that the Parties may adopt regarding baselines, leakage and uncertainties. Aggregate emissions or removals are the sum of stock changes (net of adjustments) over all applicable land units. [2.3.2, 3.3.2]

38. An "activity-based" approach would start with the carbon stock change attributable to designated LULUCF activities. First, each applicable activity's impact on carbon stocks is determined per unit area. This impact is multiplied by the area on which each activity occurs. Adjustments may also be made to reflect policy decisions by the Parties. Aggregate emissions or removals are calculated by summing across applicable activities. The carbon stock change would be less verifiable than for a land-based approach. Potentially a given area of land could be counted more than once if it is subject to multiple activities. This could result in inaccurate accounting if the effects of activities are not additive. [2.3.2, 3.3.2, 4.3.3]
39. Alternatively the Parties could decide that each land unit could contain no more than a single activity. In this case, the combined impact of multiple practices applied in the same area would be considered a single activity. The activity-based accounting could start when the activity starts, and end when the activity ends. Stock changes prior to the start of the activity are not accounted, even if they occur in a commitment period. [2.3.2]
40. Only emissions and removals of carbon dioxide can be measured as changes in carbon stocks. Methane and nitrous oxide cannot be measured as stock changes. Methane and nitrous oxide emissions from many land-use activities are included in Annex A of the Kyoto Protocol, e.g., rice cultivation, enteric fermentation and agricultural soils, and in the IPCC reporting guidelines, and therefore they will be captured in national inventories. This is not the case, however, for emissions of these gases related to forestry activities and projects on Kyoto lands, which are not included in Annex A, although some of these forestry activities are discussed in the 1996 Revised IPCC Guidelines for National Greenhouse Gas Inventories. If these effects are not considered, the full impact of forestry activities may not be reflected in the Kyoto accounting system. Similarly, to accurately assess the climate benefits of projects in non-Annex I parties changes in methane and nitrous oxide emissions should be accounted if project activities cause the fluxes of these gases to increase. [2.3.2, 3.3.2]
41. Relevant carbon pools are those that are affected by activities and projects. These include above-ground biomass, litter and woody debris, below-ground biomass, soil carbon and harvested materials, but the degree of impact may vary significantly between activities and types of projects. While methods exist to measure all carbon pools, monitoring is not routinely performed and the costs vary significantly. To reduce monitoring costs, the Parties may decide that selective accounting of carbon pools, consistent with the objectives of the UNFCCC, could be used by including all those pools anticipated to have reduced carbon stocks while neglecting selected pools anticipated, with a sufficient level of certainty, to have unchanged or increased carbon stocks. Similar criteria could be used for fluxes of non-carbon dioxide greenhouse gases. The requirements for verifiability in the Protocol mean that only carbon pools that can be measured and monitored could potentially be claimed as credits. [2.3.7, 3.3.2, 4.2.1]
42. Measurement uncertainty could be addressed by adjusting estimated stock changes. A precautionary approach would adjust the estimate in the direction that is likely to understate increases and overstate decreases in stocks. This would allow individual parties to make trade-offs between increased monitoring costs and the potential to receive increase carbon credits or reduce debits. If "good practice" methodologies for measuring the impact of LULUCF activities are developed and adopted it could be decided that estimates made in conformity with this methodology would not be subject to an uncertainty adjustment. [2.3.7, 3.4.4, 5.4.4, 6.5.2]
43. Changes in carbon stocks in wood products could potentially be accounted as part of the activity that is the source of the wood products or as an independent wood products management activity. If management of wood products is treated as an additional activity under Article 3.4 then it may be necessary to exclude wood products from accounting under other Article 3.3 or 3.4 activities to avoid double counting. Once wood products are in trade, their source will seldom be traceable. If changes in wood product pools are not accounted, i.e. assumed that the carbon is lost immediately, the system will not account for a potentially important pool. [2.4.2, 3.3.2, 4.5.6, 6.3.3 and Table 3 of this SPM]

44. Enhancement of carbon stocks resulting from land-use, land-use change and forestry activities is potentially reversible through human activities, disturbances or environmental change. This reversibility can be accounted for by ensuring that any credit for enhanced carbon stocks be balanced by accounting for subsequent reductions in those carbon stocks, regardless of the cause. [2.3.6, 3.3.2]
45. Contiguous commitment periods would avoid incentives to concentrate activities that reduce carbon stocks in time periods that were not covered. [2.3.2]
46. Policies by governments or other institutions (e.g., land tenure reform and tax incentives) provide conditions and incentives for implementing LULUCF activities. The ability to measure the impact of these conditions and incentives will depend, in part, upon the carbon inventory and monitoring system in each country. However, it may be very difficult for countries to assess the relative contribution of such policies or institutions compared to other human and natural factors that drive changes in carbon stocks. [2.3.5, 5.2.2]
47. Natural variability and the indirect effects of human activity, such as carbon dioxide fertilization, nutrient deposition, or climate-induced changes in disturbance regimes, could significantly affect carbon stocks during a commitment period on Kyoto lands. [2.3.3]
48. The Kyoto Protocol specifies that accounting under Article 3.3 be restricted to certain "direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation" (ARD land) occurring since 1990. It is unclear whether "direct human-induced" refers only to the activities leading to the creation of ARD land or also to the processes leading to changes in carbon stock on ARD land. The Parties may wish to decide whether non-direct human-induced impacts on stock changes on ARD land should be accounted or not. However, Parties need to recognize that for activities that involve land-use changes, (e.g. from grassland/pasture to forest) it is very difficult, if not impossible, to distinguish with present scientific tools that portion of the observed stock change that is directly human-induced from that portion that is caused by indirect and natural factors. [2.3.4, 3.3.2]
49. For those activities where only narrowly-defined management changes under Article 3.4 are involved (e.g. conservation tillage) and the land use remains the same, it may be feasible to partially factor out natural variability and indirect effects. One approach may be to subtract the stock changes on comparison plots where there have been no changes in management practice from changes measured on plots with modified management activities. In most cases experimental manipulation or paired plots can be used for this purpose but they are likely to be expensive to apply over large areas. Ecosystem models can also be used but need further improvement to decrease uncertainties. [2.3.4, 4.3.4]
50. If the concept of a baseline is applied in national accounting for additional activities under article 3.4, there are many options, which include:(1) the stock/flux change that would have resulted from "business-as-usual" activities; (2) the stock/flux change that would have resulted from the continuation of 1990 activity levels; (3) the stock/flux change that would result in the absence of active management; (4) performance benchmarks or standard management practice; (5) the rate of change of stocks/fluxes in 1990. One difficulty with the use of counterfactual baselines is verification. [2.3.4, 4.6]
51. Another option for implementing Article 3.4 is a project-based approach that uses a baseline to limit credits to carbon benefits that are "additional" to what would have otherwise occurred. Article 3.4 refers to additional activities not project based activities and unlike Articles 6 and 12, there may be no requirement that these activities are "additional" to what would have occurred against a business as usual baseline. The use of a project-based approach to Article 3.4, as opposed to a national approach, would increase the potential for leakage of project benefits, although experience indicates ways to minimize such leakage. [2.3.2, 4.6, 5.3.3]
52. The definition of the term land-use change in Article 3.7 will determine which emissions and removals of carbon will enter the 1990 base year or period for some countries. If land-use change is defined to encompass more than conversion between forest and non-forest, then those activities (e.g. the conversion of grasslands to croplands) will be included in the 1990 base year or period. If these same activities are not included under Article 3.3 or 3.4

during the commitment periods, then the inventories of countries subject to this clause in Article 3.7 would not be calculated on the same basis as their 1990 emissions base year or period. [3.3.2]

53. If different accounting rules are adopted for Articles 3.1, 3.3, or 3.4, additional decision rules may be needed to determine which accounting rule applies to land that, over time, is subject to multiple types of activities. For example, one set of accounting rules could be given primacy in cases where more than one set could potentially apply and double counting might result. [2.3.2, 3.3.2]

54. Leakage is the failure to capture greenhouse gas changes outside the accounting system that result from greenhouse gas changes within the system. If the emissions from the diverted activity fall outside the accounting system, then system measures will fail to give an accurate assessment of the true aggregate changes. For instance, forest protection measures may be used to sequester or reduce the emission of carbon from lands within the accounting system, where-as market forces may simply shift the extractive activity elsewhere. As the spatial and temporal scale of accounting increases, leakage errors generally become less significant (i.e., there is less activity that falls outside the system). Leakage is of particular concern in project-level accounting, but can also, but to a lesser extent, occur with activities under Articles 3.3 and 3.4. Leakage (from Annex I to non-Annex I) could also be an issue in other sectors, but it is not assessed in this document. [2.3.5, 5.3.3]

Part III

5. Methods for Measuring and Monitoring

55. Kyoto lands can be identified and reported using geographical and statistical information. For lands so identified, carbon stocks and their changes over time can be estimated using some combination of direct measurements, activity data, and models based on accepted principles of statistical analysis, forest inventory, soil sampling, and ecological surveys. These methods vary in accuracy, precision, cost, and scale of application. The cost of measuring changes in carbon stocks for a given area increases as both desired precision and landscape heterogeneity increase. [2.4, 3.4]

56. The spatial resolution of monitoring has important implications. If the size of sampled land areas is small, the task and cost of monitoring can become very demanding. If the sampling resolution is set at a coarse scale, the data demands can be modest, but significant areas subject to an activity may be lost in the averaging process. For example, if canopy cover is assessed over land areas of 100 ha, then deforestation of smaller areas within a unit may not take the canopy cover of the unit below the forest definition threshold and thus changes in carbon stocks may not be counted. Likewise, afforestation or reforestation of smaller areas will not be counted. Hence, there are clear trade-offs between an accurate and precise assessment of changes in carbon stocks and cost. However, an appropriate design should result in a statistically-reliable estimate. [2.2.2]

57. The technical capacity required by Annex I parties to measure, monitor, and verify carbon stock changes under the Kyoto Protocol will be significantly affected by decisions of the Parties regarding definitions of key terms. It will also depend on decisions on additional activities that may be included under Article 3.4, and whether additional activities are defined broadly or narrowly. [2.4.1, 3.4, 4.3.2]

58. Annex I parties generally have the basic technical capacity (periodic soil and forest inventories, land-use surveys, and information based on remote sensing and other methods) to routinely measure carbon stocks in terrestrial ecosystems. Some countries may use existing capacity with minimal modification to implement the various Articles in the Kyoto Protocol, but others may need to significantly augment existing systems to develop operational systems. Most non-Annex I countries may not have the technical, institutional and financial capacity needed for measuring and monitoring carbon stock changes and would require assistance. [2.4.6, 3.4.3, 4.2]

59. Methods for measuring changes in forest carbon stocks in above ground biomass over a five-year commitment period are sensitive enough to serve the requirements of the Protocol. Sensitive methods for measuring below-

ground carbon stocks also exist. Changes in soil carbon stocks over a five year period can be measured in most soils, especially through adoption of appropriate sampling techniques, which are designed to overcome spatial variability. Methods that further improve soil and vegetation carbon stock measurements will depend on research and development and are likely to be highly transferable between parties. [2.4.2, 2.4.3, 4.2.2, 5.4.1]

6. Carbon Potential of ARD and Additional Activities

6.1. Afforestation, Reforestation, and Deforestation

60. Different definitions and accounting systems produce different estimates of potential changes in carbon stock accounted. Table 2 shows best estimates for changes in carbon stock accounted due to ARD activities under both IPCC and FAO definitional scenarios and with three different carbon accounting approaches applied to the FAO scenarios. The definitional scenarios were not chosen to anticipate the Parties' decisions, but to illustrate with available data the potential differences encountered. [3.5.3, 3.5.4.]
61. Under the IPCC definitional scenario, if Annex I parties (approximated by adding the estimates for boreal and temperate latitudes from Table 2) maintain current rates of afforestation and reforestation from 1990 through 2010, the rate of increase in carbon stocks from these activities could be about 180 Mt C y⁻¹. Under the same assumptions, this could be offset by decreases in carbon stocks from deforestation of about 75 Mt C y⁻¹, producing a net increase of 105 Mt C y⁻¹. If the current rates of afforestation and reforestation are doubled and the rates of deforestation halved from the year 2000, then the rate of net increase in carbon stocks from these activities could be 230 Mt C y⁻¹ in Annex I countries. [3.5.4]
62. Under the FAO definitional scenario and using three different accounting systems, very different estimates result. If Annex I Parties maintain current rates of afforestation and reforestation from 1990 through 2010, the accounted changes in carbon stocks would range from -3450 Mt C y⁻¹ to +2600 Mt C y⁻¹: with decreases in carbon stocks from deforestation of about 75 Mt C y⁻¹, producing a net change of about -3525 Mt C y⁻¹ to +2525 Mt C y⁻¹. None of the accounted carbon stock changes are consistent with carbon dioxide changes that would occur in the atmosphere.
63. For comparison purposes, if current rates of afforestation and reforestation are maintained in non-Annex I countries (approximated by the estimates for tropical latitudes in Table 2), carbon stock increases using the IPCC definitions are about 360 Mt C y⁻¹ and decreases from deforestation about 1500 Mt C y⁻¹ producing a net decrease of about 1140 Mt C y⁻¹. If afforestation and reforestation rates are doubled from the year 2000 and deforestation rates halved, then the increase from afforestation and reforestation could be about 540 Mt C y⁻¹ and the decrease from deforestation about 750 Mt C y⁻¹ (i.e. net emissions of about 200 Mt C y⁻¹ compared to emissions of over 1100 Mt C y⁻¹ under current rates). [3.5.4]

Table 2: Potential carbon stock changes from ARD activities.

The estimates refer to above and below ground biomass carbon; all numbers have been rounded. [3.5.4]

		A & R average sequestration rate during the first commitment period (t C ha ⁻¹ y ⁻¹) ^a	Current annual area subject to activity (Mha)		Average annual carbon stock change accounted for the first commitment period (Mt C y ⁻¹) ^d	
		D Average Carbon Stock (t C ha ⁻¹)	Under FAO ^b Definitions	Under IPCC ^b Definitions	Under FAO Definitions ^c	Under IPCC Definitions
High Latitudes, mostly boreal forests	A & R	1.5	3.2	0.06	-255 to +100	2
	D	30	0.01	0.01	-0.3	-0.3
Mid-latitudes, mostly temperate forests	A & R	4.0	31	2.2	-3200 to +2500	180
	D	60	1.25	1.25	-75	-75
Low Latitudes Mostly tropical forests	A & R	6.5	NA	2.7	NA	360
	D	90	16	16	-1500	-1500

^a The sequestration rates are the best estimates for the first commitment period in forests planted after 1990, which are higher than over a full rotation cycle, from a variety of sources; the ranges for high, mid and low latitudes were 0.8-2.4, 0.7-7.5 and 3.2-10 t C ha⁻¹y⁻¹ respectively.

^b In the FAO scenario the harvest-regeneration cycle creates ARD land; in the IPCC scenario ARD is created only by land-use change associated with forest / non-forest conversions, i.e. it excludes harvest-regeneration cycle.

^c The range of values shown using the FAO definition, arises from using three different accounting systems (see Chapter 3). None of the accounted carbon stock changes are consistent with carbon dioxide changes that would occur in the atmosphere.

^d Average annual stock change for the first commitment period has been calculated for A & R as the product of average annual sequestration rate, the 20 years between 1990 and 2010, and the current area converted. For example, annual A & R activities on 0.06 Mha in high latitudes under the IPCC definitions for 20 years, sequestering 1.5 t C ha⁻¹y⁻¹ would produce annual sequestration of about 1.8 Mt C y⁻¹ (rounded to 2 in the table) during the first commitment period. Deforestation stock changes are calculated simply as the average stock multiplied by the current annual rate. For example, annual deforestation of 0.01 Mha in high latitudes (with 30 t C ha⁻¹) would result in annual emissions of 0.3 Mt C y⁻¹.

6.2. Additional Activities

64. Estimating the potential impact of additional activities that might be allowed under Article 3.4, rests on the decisions adopted by the Parties. In Table 3, it is assumed that all activities affecting the carbon stocks on managed lands are included, except for those that might fall under Article 3.3 on forest land, and that activities are broadly defined. The figures are gross estimates, including direct and indirect effects, and are clearly subject to considerable uncertainty. No attempt was made to factor out such effects as the impacts of climate change. [4.4]

65. Opportunities for net carbon benefits exist in both Annex I and non-Annex I countries through improving management practices in forestry (in addition to those from Article 3.3 activities), grazing lands, and cropland. An opportunity largely limited to non-Annex I countries is in practicing agroforestry on land undergoing land-

- 1 use change. Another opportunity in both Annex I and non-Annex I countries will occur if wood products are
- 2 included in the accounting system [Table 3 in this SPM] .
- 3
- 4 66. The potential impact of additional activities in Annex I countries in the first commitment period could be up to
- 5 300 Mt C y⁻¹ from improved management within a land use and from land-use change, without including the
- 6 potential for biofuels to displace the use of fossil fuels. An additional 210 Mt C y⁻¹ could be stored off-site in
- 7 forest products. These estimates reflect expert opinion as to the potential for adoption and implementation under
- 8 aggressive, effective, and sustained policy incentives. Such estimates have high uncertainty and should be
- 9 viewed as the maximum achievable under high land-owner response to available technical opportunity (Table 3).
- 10 The estimates also assume that the rates of carbon sequestration remain constant over long periods of time. [4.4]
- 11
- 12 67. Globally, in Annex I and non-Annex I countries, the potential impact of additional activities could be up to
- 13 1300 Mt C y⁻¹ by 2010. [4.4, Table 3 this SPM]
- 14
- 15 68. The estimates in Table 3 are for net changes in carbon stocks in vegetation and soils, and do not include the
- 16 associated emissions of non-CO₂ greenhouse gases that can be significant in many cases such as management of
- 17 agricultural soils or wetlands, neither do they include the impact of the use of biofuels in reducing fossil fuel
- 18 emissions. Analyses of net greenhouse gases should help identify the full effect of particular activities. [Table 4-
- 19 3]
- 20
- 21 69. Commitments under the Kyoto Protocol require Annex I parties to reduce emissions by about 200 Mt C y⁻¹
- 22 below 1990 levels and about 750 Mt C y⁻¹ below business-as-usual projections based on the IPCC IS92a
- 23 scenario. A simple comparison suggests that the potential impact of Article 3.3 and 3.4 activities in Annex I
- 24 countries alone could be comparable to the projected magnitude of reductions required by Annex I Parties. Such a
- 25 comparison, however, risks under-estimating the difficulty in creating and implementing the incentives needed to
- 26 achieve the potential.
- 27

Table 3: Potential* net carbon storage of improved management, changed land use, and offsite storage**.

Activity (practices)	Group ¹	Area ²	Adoption / conversion	Rate of C gain ²		Potenti al
		10 ⁶ ha	% of area by 2010	t C ha ⁻¹ y ⁻¹		Mt C y ⁻¹
a. Improved management within a land use						
Cropland (reduced tillage, rotations and cover crops, fertility management, erosion control, and irrigation management)	A-1	589	40		0.32	75
	NA-1	700	20		0.36	50
Rice paddies ³ (irrigation, chemical and organic fertilizer, and plant residue management)	A-1	4	80		0.10	<1
	NA-1	149	50		0.10	7
Agroforestry ⁴ (better management of trees on croplands)	A-1	83	30		0.50	12
	NA-1	317	20		0.22	14
Grazing land (herd, woody plant and fire management)	A-1	1297	10		0.72	93
	NA-1	2104	10		0.80	168
Forest land (forest regeneration, fertilization, choice of species, reduced forest degradation)	A-1	1898	10		0.53	101
	NA-1	2153	10		0.31	69
Urban land (Tree planting, waste management,)	A-1	50	5		0.3	1
	NA-1	50	5		0.3	1
TOTAL within a land use	A-1					282
	NA-1					309
b. Land-use change						
Agroforestry (Conversion from unproductive cropland and grasslands)	A-1	-0	-0		-0	0
	NA-1	630	20		3.1	391
Restoring severely degraded land ⁵ (to the point where it can function as crop-, grass-, or forest land)	A-1	12	5		0.25	<1
	NA-1	265	5		0.25	3
Grassland (conversion of cropland to grassland)	A-1	602	5		0.8	24
	NA-1	855	2		0.8	14
Wetland restoration (conversion of drained land back to wetland)	A-1	210	5		0.4	4
	NA-1	20	1		0.4	0
TOTAL land-use change	A-1					28
	NA-1					408
c. Off-site carbon storage						
Forest products	A-1	n.a.	n.a.		n.a.	210 ⁶
	NA-1	n.a.	n.a.		n.a.	90
Totals	A-1					520
	NA-1					807
	Global					1327

- * The term "potential" as used in this table reflects expert judgement as to the maximum that might be achieved with these activities under an effective, sustained, and global set of incentives designed to maximize implementation of the activities. These estimates should be viewed as highly uncertain, with the error likely to be in over-stating the actual impacts that can be realized.
- ** This table does not include the potential for biofuels to displace the use of fossil fuels, which has been estimated to be in excess of 1Gt C y⁻¹ during the coming decades
- ¹ A-1 = Annex-1 countries; NA-1 = non-Annex-1 countries; n.a. = not applicable.
- ² Areas for cropland, grazing land and forest land were taken from IGBP-DIS global land cover database derived from classification of AVHRR (Advanced Very High Resolution Radiometer) imagery. Each land-use/land cover type was subdivided by the climatic regions defined in Table 4.3, using a global mean climate database of temperature and precipitation, with additional calculations of potential evapotranspiration. Each climatic region was further subdivided by Annex-1 and non-Annex-1 countries. Modal rate estimates from Table 4.3 were then weighted by the relative area of each land use by climatic region for Annex I and non-Annex I countries, to derive a global area-weighted mean rate for each land use.
- ³ Riceland area was subtracted from cropland area.
- ⁴ Of the 400 Mha presently in agroforestry, an estimated 300 Mha are included in the land cover classification for cropland and the remaining 100 Mha are included in the forest land cover. These areas were subtracted from the respective totals for cropland and forest land.
- ⁵ Assumes that severely degraded land is not currently classified as cropland, forest land, or grassland
- ⁶ The estimates for 2040 are highly uncertain, as they will be significantly affected by policy decisions.
- ⁷ For some activities that could be allowed under Article 3.4, the rates of carbon gain will diminish with time, typically approaching zero after 20 to 40 years. The values shown in Table 3 are the average rates during this period of accumulation.

7. Project-Based Activities

70. Experience is being gained in LULUCF projects that are under initial stages of implementation in at least 19 countries. Table 4 summarizes 25 projects, mostly forestry projects in the tropical countries, with estimated carbon benefits ranging from 4 to 330 t C ha⁻¹ over project lifetimes of 16-99 years. Reported total investment to date in these projects is about US\$150 million, and could grow to \$330 million, at which point the total area would be 6.4 Mha. Estimated cost of carbon benefits over the project lifetime (i.e., total undiscounted project costs divided by estimated carbon benefits) ranges from \$US 1-28 per tonne of carbon with an average of about \$US 8 per tonne of carbon. [5.2.2, 5.2.3]
71. Estimates of costs and greenhouse gas benefits in projects will change as standardized information, experience, and methods are developed and decisions made by the Parties on requirements and modalities for implementing Articles 6 and 12 of the Kyoto Protocol. [5.2.2, 5.2.3]
72. Experience to date suggests that the transfer of technologies including software, hardware, knowledge, and new skills is an important component for implementing many projects. The most effective are those appropriate to the needs of the recipient countries and communities, raising the skills and knowledge base in the community, and taking advantage of local experience. [5.6.4]
73. A number of approaches have been used during the Activities Implemented Jointly (AIJ) Pilot Phase for establishing baselines and evaluating additionality of LULUCF projects. Options include whether baselines are to be project specific or sectoral (based on aggregated national data, similar to the benchmarking approach used in the energy sector); whether they are to remain fixed throughout the duration of a project or be periodically adjusted; and which methodology to use for the quantification (or estimation) of stock changes in the baseline. [5.3.2., Table 5-4]

Table 4: Cost and carbon mitigation of selected AII pilot phase
and other LUCF projects in some level of implementation.

Project Type	Land Area (Mha)	Carbon Mitigation (Mt C)	Costs \$ t ⁻¹ C	Carbon Mitigation over project lifetime t C ha ⁻¹
Emissions Avoidance via Conservation:				
Forest Protection (7*)	2.9	40-108	0.1– 15	4 - 252
Forest Management (3*)	0.06	5.6	0.3 – 8	40 - 85
Carbon Sequestration				
Reforestation and Afforestation (7*)	0.10	12	1 – 28	26 - 328
Agroforestry (2*)	0.2	10.8	0.2-10	56-165
Multi-Component and Community Forestry (2*)	0.53	20-49	0.2 – 15	0.2 –165

* Number of projects. Figures taken from project reports and published project reviews. Cost and carbon mitigation figures have been estimated using different methodologies and may not be comparable.

74. Experience shows that reducing access to food, fiber, fuel and timber resources without offering alternatives may result in project leakage as people move elsewhere to find needed supplies. A few pilot projects are designed to reduce leakage by explicitly incorporating components that supply the resource needs of local communities (e.g., establishing fuelwood plantations to reduce pressures on other forests), and that provide socio-economic benefits that create incentives to maintain the project. [2.3, 5.3.3]
75. Project accounting and monitoring methods can be matched with project conditions to address leakage issues. For example, if flows of LULUCF products or people across project boundaries are negligible, leakage is likely to be small, and the monitoring area can be set roughly equal to the project area. Conversely, where there are significant flows and leakage is likely, the monitoring area will need to be expanded beyond the project area to account for the leakage. [5.3.3]
76. Alternative approaches for accounting and monitoring leakage may be required where monitoring and project areas cannot be easily matched. Potential options include: (a) national or regional benchmarks (empirically-based values that relate leakage levels to activities and/or regions) to adjust for estimating leakage outside the project area; and (b) standard risk coefficients developed by project or activity type and region and adjusting project greenhouse gas benefits accordingly. [5.3.3]
77. To be effective LULUCF projects should result in long-term impacts on greenhouse gases concentrations in the atmosphere. Different approaches have been proposed to define the duration of project greenhouse gas benefits: (a) they should be maintained in perpetuity because their "reversal" at any point in time would partly invalidate a project; (b) they should be maintained for a period of 100 years to be consistent with the timeframes adopted in the Kyoto Protocols for the calculation of Absolute Global Warming Potential values; (c) they should be maintained until they counteract the effect of an equivalent amount of greenhouse gases emitted to the atmosphere; and (4) they may vary over different operational timeframes as has been the approach adopted during the AII Pilot Phase. Parties may need to develop guidelines on how to calculate the greenhouse gas benefits of projects that are conducted for short periods of time [5.3.4].
78. Several approaches have been used to account for the greenhouse gas benefits over the lifetimes of LULUCF projects: (a) calculating the difference in carbon stocks between a project and its baseline at a given point in time; (b) the average storage method has been used for dynamic systems, e.g., in which planting, harvesting and replanting operations take place; (c) credit only a fraction of the total greenhouse gas benefit for each year that the project is maintained, e.g., based on an equivalency factor by analogy to Global Warming Potentials, i.e.,

tonne year carbon accounting. Depending on the accounting method used, different amounts of carbon benefits accrue to the project at different times [5.4.2, Table 5-9].

79. LULUCF projects are subject to a variety of risks and uncertainties. Some of these are inherent to particular land-use activities (e.g., fires and pests for forests), while others are applicable to greenhouse gas mitigation projects in both LULUCF and energy sectors (political and economic risks). These risks and uncertainties can be estimated and greenhouse gas benefits adjusted, or mitigated through project design, diversification of project portfolios, or insurance methods. [5.3.5]

80. The costs to measure and monitor carbon pools in LULUCF projects are mainly a function of the desired precision level, which varies by project type, size of the project, distribution of the project lands (contiguous or dispersed), and the natural variation within the various carbon pools. In a few forestry projects in tropical countries, project developers have, in the early stages of project implementation, measured and monitored relevant above- and below-ground carbon pools to precision levels of about 10% of the mean at a cost of about US\$1 to US\$5 per hectare and US\$0.10 - US\$0.50 per tonne of carbon. The attainable accuracy and precision of carbon measurements and monitoring is likely to be similar among LULUCF project types, but differing measuring and monitoring costs result from decisions about which particular carbon pools are to be measured and monitored and their variability. [5.4.4]

81. Projects need not be developed solely by large organizations or on large land areas. Experience from a few projects suggests that it may be possible to assemble groups of small farms or diverse land-use activities over dispersed lands into projects with existing measurement and monitoring practices. [5.2.2, 5.4.1]

8. Reporting Guidelines for the Relevant Articles of the Kyoto Protocol

82. Under Article 5.2 of the Protocol, the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Guidelines) provide the basis for the accounting of anthropogenic emissions by sources and removals by sinks of all greenhouse gases, not controlled by the Montreal Protocol. These Guidelines were developed to report national greenhouse gas inventories under the UNFCCC, not for the Kyoto Protocol. The principles of the Guidelines include: completeness, comparability, transparency and accuracy. Depending on the decisions made by the Parties, it is likely that improvements to the Guidelines, and/or provision of additional information for the application of the Guidelines, will be needed for reporting under the Protocol. [6.1.1, 6.5.2]

83. The Guidelines apply the principles of symmetric accounting for a land area affected by an activity for all reported pools, i.e. they quantify both sources and sinks of greenhouse gases. Both activities and land areas are required for accounting in the LUCF sector. The Guidelines can provide the basis for a 'land-based' or 'activity-based' accounting system for reporting under the Protocol. [6.3.2]

84. The Guidelines consist of three volumes, the Reference Manual, the Workbook and the Reporting Instructions. To analyze their adequacy for reporting under the Protocol, there is a need to distinguish between them. The Reference Manual provides a comprehensive approach to account for national changes in carbon stocks in all terrestrial pools (i.e., above- and below- ground biomass, soil, soil surface litter, and harvested wood products) in forests, grasslands, shrub-lands and agricultural lands. The Guidelines encourage the use of national data but provide default data that were designed for use by all Parties. The use of national data is likely to increase the accuracy of estimates in the changes of carbon stocks and emissions and removals of greenhouse gases. [6.1.1]

85. The Workbook contains accounting methods and default data for calculating a subset of carbon pools, e.g., the above-ground biomass and the carbon in the top 0.3 meter of the soil. The Workbook does not provide explicit accounting methods or default data for below-ground biomass, deep soil carbon, soil surface litter, and harvested wood products, nor for the effects of fire or other disturbances. The IPCC has identified three approaches for accounting the emissions and removals of carbon dioxide from wood products, i.e., (a) stock-change approach, (b) production approach, and (c) atmosphere-flow approach. Further work, however, cannot be initiated until there is guidance from the Parties on which, if any, of the approaches is to be adopted. The use of methods and

default data for soil carbon down to only 0.3 meter may need to be reviewed. In addition, the methods may need to be adjusted to directly link the changes in soil carbon, and other pools, with the activities that cause these changes. Accounting for other carbon pools could be important for compliance under the Protocol. [6.1.1, 6.3.1]

86. A range of definitions of ARD, several land management activities and assemblages of trees, that are relevant to Articles 3.3, 3.4, 6, and 12, are described in the Guidelines, but without provision for the "since 1990" time clause. For accounting purposes, there is no distinction between afforestation and reforestation within the Guidelines. However, the definitions of forests and activities allow considerable flexibility in interpretation and therefore do not, by themselves, ensure consistency in accounting among Parties. [6.3.1, 6.3.2, 6.4.1]
87. The Guidelines provide the framework to address several additional activities that may be included under Article 3.4. However, some additional activities can introduce definitions, default assumptions and additional carbon pools that are not adequately covered by the Workbook. To account for these additional activities, a range of improvements, from minor to significant, may be required to the Guidelines. [6.5.1]
88. The Guidelines were not intended for projects, but the approach can be applied to estimate changes in carbon stock and emissions and removals of greenhouse gases at the project level. If required by Parties, methods may be needed to establish system boundaries and estimates of leakage from project activities. Other issues to be considered include: additionality, uncertainties, transparency, verifiability, baselines and permanence. [6.4, 6.5.1]
89. The *Guidelines* do not provide methods and formats for reporting socio-economic and non-greenhouse gas environmental impacts. If the Parties decide that reporting for such impacts in the context of Article 12 is required, then significant additions to the *Guidelines* will be necessary. [6.4.1]
90. Many of the reporting issues (e.g., additionality, uncertainties, transparency, verifiability, permanence and methods for baselines) are not unique to LULUCF. The difficulties in resolving some of the issues may be similar in other sectors in Annex A of the Protocol. However, some of them may be more critical for LULUCF, particularly permanence of the carbon stocks and the difficulty in differentiating changes in carbon stock due to direct human-induced activities from those due to indirect causes and natural phenomena. The reporting for LULUCF may need to address these issues specifically. [6.1]
91. The level of uncertainty is generally higher for all greenhouse gas emissions associated with biological systems than those associated with energy and industrial systems. An underlying principle of the Guidelines is the consistent treatment and reporting of uncertainties of greenhouse gases among all sectors. However, uncertainties can be reduced with scientific and technological developments, and improvements to data collection and analysis. Efforts to reduce such uncertainties would increase the cost of preparing inventories; the Parties would need to consider the trade-offs between improved accuracy, precision, transparency, verifiability and costs. [6.1]
92. The IPCC, is addressing good practice in applications of inventory methodologies and uncertainties in sectors other than LUCF. The IPCC has a plan to initiate its work related to land-use change and forestry in response to the conclusions of the SBSTA at its Tenth and Eleventh sessions. [6.5.2]

9. Potential for Sustainable Development

93. To implement all relevant land use, land-use change and forestry Articles under the Kyoto Protocol, it is likely that Parties will face a series of decisions and tradeoffs on a broad range of environmental and socioeconomic impacts on: (1) biodiversity; (2) the quantity and quality of forest, grazing land, soil, and water resources; (3) the ability to provide food, fiber, fuel, and shelter; and (4) employment, poverty, and equity. [2.5.1, 3.6]
94. While it is difficult to generalize the impacts of LULUCF activities and projects on sustainable development across activities, locations, and time, there are a number of broad environmental and socioeconomic synergies and trade-offs that the Parties may wish to consider, such as: [2.5.1, 3.6, 5.4]

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- Converting non-forest land to forest will typically increase the diversity of flora and fauna, except in situations where biologically diverse non-forest ecosystems, such as native grasslands, are replaced by forests consisting of single or a few species. The biodiversity of plantations can be increased by measures to lengthen rotations, maintain understory vegetation, use native tree species and minimize chemical inputs, particularly herbicides and pesticides. Avoiding deforestation can provide potentially large co-benefits including the protection of biodiversity, water, and soil resources and the maintenance non-timber forest products and services [3.6.1].
 - Converting land from agricultural use to forest or avoiding the conversion of forests to agriculture, would enhance the socio-economic role of the forest sector and diminishes the role of agricultural sector. In places where agricultural land is scarce (e.g., through high population growth), the economic and social impacts could be large unless forest expansion/conservation is coupled with agricultural intensification. [3.6.2]
 - Changing the management of forests to store more carbon (or release less carbon) will alter the size and structure of forests. If more intensive forms of management are used to increase tree biomass, this may make more timber available for eventual harvest, but may also impart some negative consequences on other ecosystem functions. Alternatively, if current commercial management practices are modified to leave more biomass in the forest for longer periods of time (e.g., extended rotation lengths, reduced impact logging), other ecosystem functions may benefit while timber production is curtailed.
 - Managing agricultural soils to sequester more carbon is likely to also reduce soil erosion and increase soil fertility, thus enhancing food security for affected populations.
95. In implementing Articles 2 and 12 of the Kyoto Protocol, the Parties may decide whether or not to establish international or national criteria to ensure that LULUCF activities and projects are consistent with sustainable development objectives. For activities within countries or projects between countries, if criteria vary significantly across countries or regions, there may be incentives to locate activities and projects in areas with less stringent environmental or socio-economic criteria. [2.5.2]
96. A system of criteria and indicators could be used to assess and compare sustainable development impacts across LULUCF alternatives. However, no agreed upon set of indicators currently exists. The Parties could draw from a number of systems under development for closely related purposes, such as criteria and indicators for sustainable forest management or the U.N. Commission on Sustainable Development, to develop an assessment tool for LULUCF measures under the Protocol. [2.5.2, 3.6]
97. Several sustainable development objectives are the focus of other multilateral environmental agreements, including the UN Convention on Biological Diversity, the UN Convention to Combat Desertification, and the Ramsar Convention on Wetlands. The Parties may need to consider whether and how to ensure that LULUCF definitions, activities and projects are implemented in a manner that is consistent with the goals and objectives of these Conventions and other relevant international agreements. [2.5.2]
98. Some of the more formal approaches to sustainable development assessment² that could be applied at the project-level include: environmental and socio-economic impact assessments, ISO 14000, and forest certification. These methods have been applied across a wide range of activities and countries to date and could be modified to be applicable to LULUCF projects. However, their use could raise project costs and slow implementation. [2.5.2]
99. Key factors affecting the sustainable development contributions of LULUCF activities and projects include: institutional and technical capacity to develop and implement guidelines and procedures; extent and effectiveness of local community participation in development and implementation; and transfer and adaptation of technology. [5.5, 5.6]

Appendix I. Conversion Units

1 tonne (t)	1000 kilogram (kg)	10 ⁶ gram (g)	1 Megagram (Mg)
1 Megatonne (Mt)	1,000,000 t	10 ¹² g	1 Teragram (Tg)
1 Gigatonne (Gt)	1,000,000,000 t	10 ¹⁵ g	1 Petagram (Pg)
1 hectare (ha)	10,000 square metre (m ²)		
1 square kilometre (km ²)	100 hectare (ha)		
1 tonne per hectare (t ha ⁻¹)	100 gram per square metre (g m ⁻²)		
1 tonne carbon	3.67 tonne carbon dioxide (t CO ₂)		
1 tonne carbon dioxide	0.273 tonne carbon (t C)		
1 tonne	0.984 imperial ton	1.10 US ton	2,204 pound
1 hectare (ha)	2.471 acre		
1 square kilometre (km ²)	0.386 square mile		
1 tonne per hectare (t ha ⁻¹)	892 pound per acre		

Appendix II. Relevant Portions of Kyoto Protocol Articles Discussed in this Special Report
 [Note: Concepts in bold are discussed in the Summary For Policymakers.]

Article 2.1: Each Party included in Annex I in achieving its quantified emission limitation and reduction commitments under Article 3, in order to promote sustainable development, shall:

(a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:

(ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements; promotion of sustainable forest management practices, afforestation and reforestation.

(iii) Promotion of sustainable forms of agriculture in light of climate change considerations

(b) Cooperate with other such Parties to enhance the individual and combined effectiveness of their policies and measures adopted under this Article, pursuant to Article 4, paragraph 2(e)(i), of the Convention. To this end, these Parties shall take steps to share their experience and exchange information on such policies and measures, including developing ways of improving their comparability, transparency, and effectiveness. The Conference of the Parties serving as the meeting of the parties to this Protocol shall, at its first session or as soon as practicable thereafter, consider ways to facilitate such cooperation, taking into account all relevant information.

Article 3.1: "The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5% below 1990 levels in the commitment period 2008-2012"

Article 3.3: The net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I. The greenhouse gas emissions by sources and removals by sinks associated with those activities shall be reported in a transparent and verifiable manner and reviewed in accordance with Articles 7 and 8.

Article 3.4: Prior to the first session of the COP serving as the meeting of the Parties to this Protocol, each Party included in Annex I shall provide, for consideration by the SBSTA, data to establish its level of carbon stocks in 1990 and to enable an estimate to be made of its changes in carbon stocks in subsequent

years. The COP serving as the meeting of the Parties to this Protocol shall, at its first session or as soon as practicable there-after, decide upon modalities, rules and guidelines as to how, and which, additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories shall be added to, or subtracted from, the assigned amounts for Parties included in Annex I, taking into account uncertainties, transparency in reporting, verifiability, the methodological work of the IPCC, the advice provided by the SBSTA in accordance with Article 5 and the decisions of the COP. Such a decision shall apply in the second and subsequent commitment periods. A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided that these activities have taken place since 1990.

Article 3.7: In the first quantified emission limitation and reduction commitment period, from 2008 to 2012, the assigned amount for each Party included in Annex I shall be equal to the percentage inscribed for it in Annex B of its aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A in 1990, or the base year or period determined in accordance with paragraph 5 above, multiplied by five. Those Parties included in Annex I for whom land use change and forestry constituted a net source of greenhouse gas emissions in 1990, shall include in their 1990 emissions base year or period, the aggregate anthropogenic carbon dioxide equivalent emissions minus removals in 1990 from land use change for the purposes of calculating their assigned amount.

Article 5.2: Methodologies for estimating anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol shall be those accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties at its third session. Where such methodologies are not used, appropriate adjustments shall be applied according to methodologies agreed upon by the Conference of the Parties serving as the meeting of the Parties to this protocol at its first session. Based on the work of, inter alia, the Intergovernmental Panel on Climate Change and advice provided by the Subsidiary Body for Science and Technological Advice, the Conference of the Parties serving as the meeting of the parties to this Protocol shall regularly review and, as appropriate, revise such methodologies and adjustments, taking into account any relevant decisions by the Conference of the Parties. Any revision to methodologies or adjustments shall be used only for the purposes of ascertaining compliance with commitments under Article 3 in respect of any commitment period adopted subsequent to that revision.

Article 6.1: For the purpose of meeting its commitments under Article 3, any Party included in Annex I may transfer to, or acquire from, any other such Party emission reduction units resulting from projects aimed at reducing anthropogenic emissions by sources or enhancing anthropogenic removals by sinks of greenhouse gases in any sector of the economy, provided that:

Article 6.1(b): Any such project provides a reduction in emissions by sources, or an enhancement of removals by sinks, that is additional to any that would otherwise occur.

Article 12.2: The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

Article 12.3(a): Parties not included in Annex I will benefit from project activities resulting in certified emissions reductions.

Article 12.3(b): Parties included in Annex I may use the certified emissions reductions accruing from such project activities to contribute to compliance with part of their quantified emission limitation and reduction commitments under Article 3, as determined by the Conference of the Parties serving as the meeting of the Parties to the Protocol.

Article 12.5: Emissions reductions resulting from each project activity shall be certified by operational entities to be designated by the COP serving as the meeting of the Parties to this Protocol, on the basis of:

Article 12.5(b): *Real, measurable, and long-term benefits related to the mitigation of climate change; and*

Article 12.5 (c): *Reductions in emissions that are additional to any that would occur in the absence of the certified project.*

Appendix III. Glossary

Accuracy

The degree to which the mean of a sample approaches the true mean of the population; lack of bias (q.v.).

Activity

An ensemble of practices that take place on a delineated area over a given period of time.

Bias

Systematic over- or under- estimation of a quantity.

Biosphere

That portion of the Earth and its atmosphere capable of supporting life. The parts of the global carbon cycle that include living organisms and derived organic matter (e.g., litter, detritus, soil).

Carbon Flux

Transfer of carbon from one carbon pool to another in units of measurement of mass per unit area and time, for example $t\ C\ ha^{-1}\ y^{-1}$.

Carbon Pool

A reservoir (q.v.). Any system which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, organic soils, atmosphere. The units are mass, for example $t\ C$.

Carbon Stock

The absolute quantity of carbon held within a pool at a specified time.

Land Cover

The observed physical and biological cover of the Earth's land as vegetation or man-made features.

Land Use

The total of arrangements, activities, and inputs undertaken in a certain land cover type (a set of human actions). The social and economic purposes for which land is managed, e.g., grazing, timber extraction, conservation.

Permanence

The longevity of a carbon pool and the stability of its stocks, given the management and disturbance environment in which it occurs.

Practice

An action or set of actions that affect the land, the stocks of pools associated with it or otherwise affect the exchange of greenhouse gases with the atmosphere.

Precision

The repeatability of a measurement; e.g. the standard error of the sample mean.

Reservoir

A pool (q.v.).

Sequestration

The process of increasing the carbon content of a carbon pool other than the atmosphere.

Sink

Any process or mechanism which removes a greenhouse gas an aerosol or a precursor of a greenhouse gas from the atmosphere. A given reservoir (q.v.) can be a sink for atmospheric carbon if, during a given time interval, more carbon is flowing into it than is flowing out.

Source

Opposite of sink (q.v.). A carbon reservoir (q.v.) can be a source of carbon to the atmosphere if less carbon is flowing into it than is flowing out of it.

Table 3-1: Descriptions and implications of definitional scenarios.

Definitional scenario	Description	General implications
FAO	<u>Forest</u> : lands that have, or will have due to continued growth, more than 10% canopy cover. <u>Deforestation</u> is the decline of canopy cover to below 10%, <u>reforestation</u> is artificial establishment of forest on lands that had them previously (including regeneration post harvest) and <u>afforestation</u> the artificial establishment of forest on lands that were not historically forest.	1. Deforestation between 1990-2008 followed by reforestation can create credits. 2. Degradation/aggradation unaccounted for if canopy cover threshold not crossed. 3. Harvest/regeneration may create large areas of ARD lands. Many countries will report a debit for harvesting/regeneration cycles, except if rotation periods are very short or if an activity-based carbon accounting approach is used. 4. If carbon accounting starts in 2008, then conversion of high C-density forests, degradation and aggradation in the commitment period is covered. 5. Creates potential for inconsistency between Articles 3.3 and 3.7.
IPCC	<u>Forest</u> : As in FAO definition. <u>Reforestation</u> and <u>afforestation</u> require a land-use change from non-forest to forest and differ only in that afforested lands never contained forest. Reforestation does not include regeneration post harvest. <u>Deforestation</u> : conversion of forest to non-forest.	1 and 2 apply. 6. Harvest/regeneration cycle does not create ARD lands. 7. Only changes between forest and non-forest create ARD land.
Land Use	<u>Forest</u> is defined administratively or based on specific land-use activities. <u>Deforestation</u> is the conversion of forest to non-forest and <u>reforestation</u> and <u>afforestation</u> are the activities that lead to the conversion of non-forest to forest.	1, 6 and 7 apply. 8. Carbon stock changes might not be considered as ARD activities if the land-use classification remains unchanged.
Land Cover	<u>Forest</u> : As in FAO definition except that regrowing stands that are below the canopy cover threshold are not counted as forest. <u>Deforestation</u> is the conversion of forest to non-forest and <u>afforestation</u> and <u>reforestation</u> are reestablishment of the minimum canopy cover.	1, 2, and 5 apply 9. Kyoto land only created when the canopy cover threshold is crossed. Therefore the time when ARD land is created differs from the FAO scenario. 10. Harvest/regeneration may create large areas of ARD lands. Many countries will report a debit for harvesting/regeneration cycles, except if rotation periods are very short (< 20 years). 11. Conversion of high C-density forests, degradation and aggradation in the commitment period is covered.

Flexible	<u>Forest</u> : as FAO definition but countries have flexibility in choosing the threshold (e.g., based on C content of aboveground living woody biomass ($tC\ ha^{-1}$), tree height, and/or canopy cover). ARD defined as in IPCC scenario.	1, 2, 6 and 7 apply. 12. Gives countries flexibility in selecting a definition of forest. Allows use of existing data thus reducing costs. Countries could choose a threshold in order to maximize credits or minimize debits.
Degradation /aggradation	<u>Forest</u> : Defined in C density or canopy cover classes (e.g. 10 to <40, 40 to <70 % canopy cover). <u>Deforestation</u> is decrease in canopy cover or C density at maturity from one class to another. <u>Reforestation</u> is the reverse and <u>afforestation</u> is the establishment of forest on lands that were non-forest for a predefined period.	1, 6, 11 apply. 13. Acknowledges differences in ecosystems by allowing the creation of ARD land in cases that would be missed by use of a uniform threshold. 14. Implementation is complex: it is difficult to establish geographically specific land-cover or C density at maturity for different times.
Biome	<u>Forest</u> : As in FAO definition, but the threshold in the definition of forest is specified by biome through e.g. an international expert panel. ARD defined as in IPCC scenario.	1, 2, 6, 7 and 11 apply.

Table 3-2: Issues, options and implications related to definition of ARD activities.

Issue, and reference to detailed text in main chapter	Options and Implications
What should be the basis for the definition of forest? (3.2; Table 3-1; more fully in 2.2.2.1)	<i>Vegetation characteristics</i> • Compatible with some countries' methods for identifying forests. • If based on actual vegetation characteristics, then the land status after clearcut harvest is always non-forest. If potential vegetation characteristics are used, then land status after clearcut harvest is forest if the vegetation is expected to return above the threshold. • Assessment of forest / non-forest based on objective, measurable criteria.
	<i>Land-use or administrative characteristics</i> • Compatible with some countries' methods for identifying forests. • Land-use designation would not necessarily reflect actual C stocks on the land. • A change in land-use designation will create ARD land, but that may or may not be associated with a change in C stocks.
Should the criterion that distinguishes forest from non-forest vary by biome, by country, or be the same for all Annex I countries? (3.2; Table 3-1)	<i>Vary by biome</i> • Threshold values must be determined for major vegetation types and/or ecosystems. • Differences in vegetation types are taken into account. • More compatible with national vegetation surveys.
	<i>Vary by country</i> • One threshold value chosen by each country, thus allowing the use of existing data. • Some vegetation types and land uses that would be regarded as forest in some countries, may be classified as non-forest in others.
	<i>Same for all Annex I countries</i> • A universal threshold would be applied for all ecosystem types and climatic zones. • Does not take into account the differences between ecosystems and climatic zones.
Should a maximum spatial assessment unit be specified? (3.4.2; 3.4.4)	<i>Yes</i> • If the spatial assessment unit is relatively large then • ARD activities affecting areas within the assessment unit may not be registered (e.g., deforestation of 89 ha within an assessment unit of 100 ha, using a crown cover threshold of 10%). This is "conservative" for AR, but underestimates emissions for D. • Monitoring costs would be low. • If the spatial assessment unit is relatively small then • Most ARD activities will be captured. • Monitoring costs could be high.
	<i>No</i> • The same issues will arise as under YES but countries' data will not be comparable, as their decisions on the size of assessment units may vary.

Should the definition of "reforestation" include or exclude the reestablishment of tree cover after clear-cut harvesting? (3.2; Table 3-1; more fully in 2.2.3.2)	<i>Include</i> • The area of ARD land will be large as areas will be added as they undergo a harvest-regeneration cycle. • Will result in unbalanced accounting at the stand and landscape levels if harvesting is not considered deforestation: actual C stock changes will not match reported changes (see Ex. Summary section 4: "landscape level" for further detail). <i>Exclude</i> • Relatively small areas of most Annex I countries will become ARD land. • There will be balanced accounting at the stand and landscape levels.
Should (re)establishment of forests through natural means be considered a form of afforestation or reforestation? (3.2; Table 3-1; more in 2.2.3.2)	<i>Yes</i> • Allows for consideration of natural regeneration, which accounts for 60% of all areas restocked in Annex I countries (82% when regeneration enhanced by planting is included; the rest is planting). • Result in more ARD area compared to the "No" option. • May encourage natural regeneration methods which lead to improved biodiversity. <i>No</i> • Restricts afforestation and reforestation to only planting activities. • Problems in distinguishing direct human-induced reforestation / afforestation are reduced because any planting or seeding activity is likely to be called direct human induced. • Results in less ARD area compared to the "Yes" option.
Should Article 3.3 include degradation/aggradation of forest land? (3.2; Table 3-1; more fully in 2.2.3.4 and 2.2.3.5)	<i>Yes</i> • Accounts for stock changes that would otherwise not be reported. • Encourages sustainable forest management. • Distinguishing silvicultural measures (e.g. thinning) from degradation/aggradation may be difficult. Thus the possibility for stock changes being double counted (under both Article 3.3 and 3.4) increases. <i>No</i> • Implementation is simplified. • Activities that significantly affect long-term forest cover without crossing a single crown-cover threshold, and the associated stock changes, are ignored under Article 3.3. • These activities may still be covered by Article 3.4.
Should the qualifier "direct human induced" refer only to the ARD activities, or also to the stock changes resulting from these ARD activities? (3.3.2.1; more fully in 2.3.3.1 and 2.3.3.2)	<i>Refer only to ARD activities</i> • All stock changes on ARD land are accounted. • Easier to implement. <i>Refer to ARD activities and to the resultant stock changes</i> • Only a part of the stock changes on ARD land are accounted. • Changes in stocks are very difficult to attribute to direct human-induced activities vs. indirect or natural effects (e.g., CO₂-fertilization, N-deposition). • Large uncertainty associated with stock changes, and great difficulty verifying them, as estimates would heavily rely on the use of models.

How should "land-use change" in Article 3.7 be defined in relation to the definition of ARD in Article 3.3? (3.3.2.8).	<i>Define ARD and "Land-use change" both as transitions between "forest" and "non-forest"</i> • Net-net approach (emissions and removals counted in the commitment period and compared against those in 1990) for Article 3.3 activities for LULUCF source countries.
	<i>Define ARD as transition between "forest" and "non-forest". Define "land-use change" as transition between e.g. 15 land categories in chapter 2 (Table 2-1)</i> • Net-net approach for Article 3.3 activities for LULUCF source countries. • Net-net approach for Article 3.4 activities possible for LULUCF source countries, if Article 3.4 activities are defined as "land-use changes".
	<i>Define ARD broadly to include regeneration after harvest. Define "land-use change" to include conversions either between "forest" and "non-forest" or between the 15-land categories</i> • Net-net approach for ARD activities that are a forest / non-forest transition. • Gross-net approach (emissions and removals counted in the commitment period but not compared against those in 1990) for all other ARD activities like regeneration after harvest.

Table 3-3: Issues, options and implications related to carbon accounting rules:

Issue, and reference to detailed text in main chapter	Options and Implications
When should the stock-change accounting for ARD activities initiated within a commitment period begin? (3.3.2.2; 3.3.2.4; 3.4; 3.5.1; 3.5.2.4; Table 3-8; Figure 3.6)	<i>Not before the initiation of an ARD activity</i> - Reported C stock changes will not always reflect actual stock changes over the commitment period (e.g. FAO scenario: may credit reforestation after harvest without debit for prior loss of forest C, see section 4 of Ex Summary: landscape level). - Requires data on C stocks at the time when the activity begins. - In the case of gradual deforestation stock changes are counted only once the non-forest threshold (e.g. 10% crown cover) is reached. <i>With the beginning of a commitment period</i> - In all scenarios except the FAO scenario accounting is balanced: FAO scenario will yield a debit for many countries (see section 4 of Ex Summary: landscape level). - Requires determination of C stock at beginning of commitment period. - Not consistent with activity-based approach.
Does ARD land remain in that category indefinitely? (3.3.2.7)	<i>Yes</i> - Ensures balanced C accounting in future commitment periods. - ARD land increases over time. - Not consistent with activity-based approach because an activity and its impacts can have a defined end. <i>No</i> - Need to define criteria under which ARD land can leave that category. - Could reduce need to quantify future C stock changes on ARD land. - If no tight guidelines are given, it could permit counting land under ARD during times of stock increases and remove it from that category during time of C losses.
Should dead organic matter and soil C pool changes be counted? (3.3.2.5)	<i>Yes</i> - Stock changes resulting from ARD activities could be larger than would otherwise be reported. - Good match between actual and reported C stock changes. - Verification of stock changes difficult/complicated. <i>No</i> - Measurements of stock changes would be less costly and less uncertain. - Less accurate representation of actual C stock changes.
Should forest products derived from ARD land be included in the accounting of C stocks? (3.3.2.5)	<i>Yes</i> - Requires use of wood products monitoring and accounting methodologies. - More complete accounting of all C pools. - Requires an agreed carbon accounting approach for wood products.

	<i>No</i> • Assessment of C stock changes is easier. • Allows wood-product management to be an activity under Article 3.4 without double counting of wood products from ARD activities.
Should all future C stock changes on ARD land be counted? (3.3.2.7)	<i>Yes</i> • Stock changes due to natural disturbances (fire, wind, insects) on ARD land would be counted. • Assessment of stock changes will be easier to implement. <i>No</i> • Reduces the reported C stock changes from non-ARD activities. • Could result in mis-match between real and reported stock changes.
Should the C credits available for R be limited if a previous D occurred on the same land between 1990 and 2008? (3.3.2.2, 3.3.2.3)	<i>Yes</i> • More balanced carbon accounting of stock changes between 1990 and 2012. • Additional data requirements (i.e., C stock in 1990 or prior to deforestation). <i>No</i> • Deforestation between 1990 and 2008, followed by reforestation would result in credits.
Should AR between 1990 and 2008 limit the C debits resulting from subsequent D, forest management or natural disturbances on this land? (3.3.2.2, 3.3.2.3)	<i>Yes</i> • More balanced C account. • Prevents potential penalty for A/R activities. <i>No</i> • Parties might incur a debit for activities that lead to long-term increases of C stocks.
How should activities under Article 3.4 be treated if they occur on land that has already undergone an ARD activity? 3.3.2.5d, 3.3.2.7 (very briefly); 3.3.2.10	<i>Consider the land under Article 3.4 and no longer under Article 3.3</i> • Allows to remove stock changes from ARD activities from the accounting under Article 3.3, which is not consistent with Article 3.3 ("shall"). • Might not be necessary in the land-based approach, because all stock changes on ARD land would be reported under Article 3.3. <i>Consider the land under Article 3.3</i> • Avoids the risk of double counting. • Eliminates the need to determine 3.4 activities on ARD land. <i>Consider the stock changes from the ARD activity under Article 3.3, and those from the 3.4 activity under Article 3.4.</i> • Risk of double counting • Difficulty of separating the stock changes according to cause.
How should ARD activities be treated if they occur on land that has already undergone an Article 3.4 activity? 3.3.2.5d, 3.3.2.7 (very briefly); 3.3.2.10	<i>Consider the land under Article 3.3 and no longer under Article 3.4</i> • Allows accounting for ARD activities on land initially in Article 3.4. <i>Consider the land under Article 3.4</i> • Not consistent with Article 3.3 ("shall"). • With the activity-based approach: ARD activities are counted neither under Article 3.3 nor under Article 3.4.

	<i>Consider the stock changes from the ARD activity under Article 3.3, and those from the 3.4 activity under Article 3.4.</i> • Risk of double counting. • Difficulty of separating the stock changes according to cause.
Should emissions of non-CO ₂ greenhouse gases be considered under Articles 3.3 and 3.7? (3.3.2.9)	<i>Yes</i> • Full impacts of ARD activities on atmospheric GHG will be considered • Increases monitoring costs. • But: non-CO₂ GHGs cannot be measured as "changes in stocks".
	<i>No</i> • Emissions of methane and nitrous oxide from AR activities (e.g., due to wetland drainage or use of fertilizers) or D activities will be missed.

Table 3-4: Definitional scenarios related to Article 3.3 and defining forest, afforestation, reforestation, and deforestation—PART 1.

	1. "FAO" Scenario	2. "IPCC" Scenario
Introduction	- Definitions of forest and ARD from the Forest Resource Assessment Programme (FRA 2000, Terms and Definitions, FAO 1998) - Definitions do not distinguish direct human induced changes, other than reforestation and afforestation which require "artificial establishment of forest...", an action which may be interpreted as a direct human activity. - Planting of trees always qualifies as afforestation or reforestation, yet the site need not be deforested prior to being reforested. - Silvicultural planting following a harvest would qualify as reforestation, but the harvest would usually not count as deforestation, i.e. symmetry between deforestation and reforestation is not maintained.	- Based on the reporting guidelines established by the Intergovernmental Panel on Climate Change (IPCC 1997). - Definitions for ARD (note specific definitions below) are land-use based with specific activity requirements e.g. planting versus regeneration through silvicultural activities. - No ambiguity in the definition of deforestation, reforestation or afforestation in that each involves direct human induced activity. - Symmetry between deforestation and reforestation.
Forest	- Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity in situ. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest. <u>Includes:</u> forest nurseries and seed orchards that constitute an integral part of the forest; forest roads, cleared tracts, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest; windbreaks and shelterbelts of trees with an area of more than 0.5 ha and width of more than 20 m; plantations primarily used for forestry purposes, including rubberwood plantations and cork oak stands. <u>Excludes:</u> Land predominantly used for agricultural practices.	Within the guidelines there exists no specific definition of forest, but rather that is left to the discretion of the reporting countries. Because it is impossible to evaluate a definitional scenario without specific language defining each term we have assumed the FAO definition of forest for purposes of our analysis, but acknowledge that the IPCC approach leaves countries free to choose their own definition of forest.
Deforestation	Refers to change of land cover with depletion of tree crown cover to less than 10 percent. Changes within the forest class (e.g. from closed to open forest) which negatively affect the stand or site and, in particular, lower the production capacity, are termed forest degradation.	- Conversion of forest to non-forest. - Note: No definition provided in the Glossary. However, the IPCC Guidelines Reference Manual states on page 5.6 that "forest and grassland conversion", i.e. the conversion of forests and grasslands to pasture, cropland, or other managed uses, is referred to as "deforestation" ... (see footnote 7 in Guidelines).
Afforestation	- Artificial establishment of forest on lands which previously did not carry forest within living memory. - Note: "Natural extension" (for example, abandoning agricultural land without direct planting), which is not included under "afforestation", does also contribute to an increase in forest area (FAO 1992). We have assumed such processes to be part of "afforestation", and their inclusion under Article 3.3 would be determined by the "direct human-induced" clause.	IPCC Guidelines Glossary: Planting of new forests on lands which, historically, have not contained forests. These newly created forests are included in the category 'Changes in Forest and Other Woody Biomass Stocks' and in the Land Use Change and Forestry module of the emissions inventory calculations.
Reforestation	Artificial establishment of forest on lands which carried forest before.	IPCC Guidelines Glossary: Planting of forests on lands which have, historically, previously

	• Note: Artificial establishment does not necessarily include natural regeneration. However, we assume that to be included, because the separation could later be made through the "direct human-induced" clause.	contained forests but which have been converted to some other use. Replanted forests are included in the category 'Changes in Forest and Other Woody Biomass Stocks' in the Land Use Change and Forestry module of the emissions inventory calculations • Note: On page 5.14 of the Reference Manual, footnote 10, a different definition of reforestation is implied. This has not been used here.
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Table 3-4: Definitional scenarios related to Article 3.3 and defining forest, afforestation, reforestation, and deforestation—PART 2.

	3. "Land Use" Scenario	4. "Land Cover" Scenario	5. "Flexible" Scenario
Introduction	- uses land-use as basis for defining forest. - Determination of the land-use status of a piece of land would need to be based on administrative procedures. - Based on a very simple structure and approach that would leave many of the decisions to national administrations. - does not explicitly require that there be symmetry between harvesting and replanting associated with forest management.	- Would lead to most intensive forest harvesting being considered as deforestation, and most forest regeneration being considered as reforestation (creates a large area of ARD lands) - Most forest management activities would create ARD lands - The definitions of reforestation and afforestation use the term "Activities that lead to ..." so that credit can be given for the increase in carbon stocks associated with reforestation and afforestation prior to reaching the Y% cover threshold required to define an area of land as forest.	allows countries to decide on the definition of a forest that they want to use, thus allowing the maximum use of existing forest inventory data. The selection of a carbon-based definition is intended to give each country the maximum flexibility in establishing their own criteria, as they can convert cover or inventory data to a carbon per unit area basis. They may select the threshold for crown cover, carbon, tree height. Also, countries may select how long a land must have been non-forest in order to qualify as reforestation.
Forest	- An area which is being managed for forest values and/or forest products, or is designated as a forest by an appropriate governmental entity. - Note: all ARD activities are assumed to be direct human induced unless demonstrated not to be the case.	An area of land that has > Y% (Y between 10 and 70%) cover of woody vegetation of (between 0 and 5) m height.	An area of land that has a minimum of Z (Z e.g. between 10 and 50) tC ha ⁻¹ aboveground living woody biomass (carbon threshold to be selected by each country) of woody vegetation, or would contain such at maturity of existing vegetation with continuation of current land use.
Deforestation	Conversion of forest to non-forest.	Conversion of forest to non-forest.	Conversion of forest to non-forest
Afforestation	Activities that lead to the conversion of non-forest to forest on lands that over the past X (e.g. 30, 50) years did not contain forest. (30 years was assumed throughout this report).	Conversion of non-forest to forest on lands that over the past X (e.g. 30, 50) years did not contain forest. (30 years was assumed throughout this report).	Conversion of non-forest to forest on lands that in 1990 [or over the past X (e.g. 10, 30, 50) years] did not contain forests
Reforestation	Activities that lead to the conversion of non-forest to forest on lands that contained forest at some time during the last X (e.g. 30, 50) years. (30 years as assumed throughout this report).	Conversion of non-forest to forest on lands that contained forest at some time during the last X (e.g. 30, 50) years. (30 years was assumed throughout this report).	Conversion of non-forest to forest on lands that in 1990 [or over the past X (e.g. 10, 30, 50) years] did contain forests

Table 3-4: Definitional scenarios related to Article 3.3 and defining forest, afforestation, reforestation, and deforestation—PART 3.

	6. "Degradation / aggradation" Scenario	7. "Biome" Scenario
Introduction	- Degradation and aggradation of a forest results in the creation of "ARD lands". - uses the FAO definition of forest along with a forest cover class transition definition of deforestation and reforestation which will result in large areas being considered ARD lands. - The selection of cover classes is based on the thresholds in widest usage. - Inclusion of regenerating forest within the definition of a forest means forest management will not result in the creation of ARD lands, unless there is long-term degradation or aggradation.	- Adjusts the definition of a forest based on the biome involved; e.g. a closed canopy temperate forest will be treated differently than a woodland savanna. - Allows deforestation to be captured more realistically across diverse forest ecosystems and to insure that there is consistency among countries. - Could allow for adjustments for data availability differences among biomes, as well as ease of data collection, both remotely and through inventory. - Specific biome based thresholds could also be set to insure that deforestation and reforestation activities are effectively captured and the creation of ARD lands based on cover change types is closely correlated with land-use activities.
Forest	FAO definition (see definitional scenario 1. "FAO").	An area of land that has A% cover of woody vegetation with >B m in height, or would contain at maturity of existing vegetation with continuation of current land use. (For each biome the minimum crown cover and tree height would need to be established that would be necessary to qualify as a forest. Determination of biome types would need to be carried out systematically through use of common criteria)
Deforestation	Decrease in potential crown cover from one cover class to another (e.g. 0 to <10, 10 to <40, 40 to <70, >70% crown cover). Potential crown cover refers to the state of the existing vegetation at maturity under continuation of current land use.	Conversion of forest to non-forest.
Afforestation	Conversion of non-forest to forest on lands that did not contain forest in 1990 (or over the past X (e.g. 30, 50) years).	Conversion of non-forest to forest on lands that in 1990 [or over the past X (e.g. 10, 30, 50) years] did not contain forests.
Reforestation	Increase in potential crown cover from one cover class to a higher cover class (e.g. 0 to <10, 10 to <40, 40 to <70, >70 % crown cover), on lands that over the past X (e.g. 30, 50) years contained forest. (30 years was assumed throughout this report). Potential crown cover refers to the state of the existing vegetation at maturity under continuation of current land use.	Conversion of non-forest to forest on lands that in 1990 [or over the past X (e.g. 10, 30, 50) years] did contain forests.

Table 3-5: Main attributes of the seven definitional scenarios utilized to illustrate the choices associated with implementing Article 3.3. Six criteria are examined and how each scenario does or does not address these issues.

Definitional Scenario	Is afforestation a land-use change?	Is reforestation a non-forest / forest change?	Is deforestation a forest / non-forest change?	Does clear-cutting create ARD land?	Does regeneration after clearcutting create ARD lands?	Can Article 3.3 and 3.7 be compatible?
FAO	In most cases	Not if regenerating following harvest	Yes	No	Yes	No [#]
IPCC	Yes	Yes	Yes	No	No	Yes
Land Use	Yes	Yes	Yes	No	No	Yes
Land Cover	In most cases	Yes	Yes	Yes	Yes	No ^{&}
Flexible	Yes	Yes	Yes	No	No	Yes
Degradation /aggrad.	In most cases	Not always if change from one forest class to another	Not always if change from one forest class to another	No	No	No ^{\$}
Biome	Yes	Yes	Yes	No	No	Yes

see also Section 3.3.2.8

\$ Reforestation is not always a land-use change, and comparability between Articles 3.3 and 3.7 is more difficult to achieve. For example, harvest/regeneration in the commitment period would create debits under the land-based approaches, but would not be counted in the 1990 baseline because it is not a land-use change. Hence more emissions would be included in the commitment period than in the baseline.

& For example, deforestation includes harvest activities where the 40% crown-cover threshold is crossed. Emissions from such harvests are counted in the commitment period but not in the 1990 baseline, because harvest does not constitute a land-use change.

\$ For example, degradation counts fully in the commitment period. However, it does not enter the 1990 baseline if degradation is not a land-use change.

Carbon sequestration in soils

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The purpose of this article is to examine (a) the magnitude of the potential for carbon sequestration in the soil as a means of reducing carbon dioxide (CO₂) in the atmosphere, (b) some of the measures that might be used to achieve this potential, (c) the methods available for estimating carbon sequestration on a farm or regional level, (d) what is needed to achieve international consensus, and (e) additional information needs.

This article is not presented as a definitive document but rather as an overview of where scientific opinion converges and where more work is needed. In addition, it aims to provoke discussion of the measures that can increase soil carbon sequestration and the policies that might be used to implement those measures.

On May 21-22, 1998, the Soil and Water Conservation Society conducted a workshop on carbon sequestration in soils with a broad group of scientists, policy analysts, and practitioners. Workshop participants reviewed and discussed the original draft of this paper. This version reflects modifications from the workshop.

One of the goals of this article is to provide a more definitive consensus on the extent to which carbon sequestration in soil can contribute to greenhouse gas mitigation and to help Canada and the United States meet their targets under the Kyoto Protocol to the Framework Convention on Climate Change of December 1997. An equally important goal is to identify governmental and private sector policies that can promote soil carbon sequestration. If similar actions can achieve both carbon sequestration and agricultural

production increases, much progress may be possible.

Atmospheric concentrations of CO₂ and other greenhouse gases (GHGs) can be lowered by reducing emissions or by taking CO₂ from the atmosphere via photosynthesis and sequestering it in different components of terrestrial, oceanic, and freshwater aquatic ecosystems. In 1992, nearly all countries of the world signed the Framework Convention on Climate Change, and more than 160 nations have subsequently ratified this agreement. Its long-term goal is to "stabilize atmospheric concentrations of GHGs at a level that will prevent dangerous anthropogenic interference with the climate system."

As a step toward this goal, countries adopted the Kyoto Protocol in December 1997. To come into force, this protocol must be formally ratified by 55 Parties to the Convention, including enough Parties listed in Annex 1 (industrialized countries) to account for 55% of CO₂ emissions in 1990. Only Annex 1 Parties have commitments to reduce emissions between 2008 and 2012 by various amounts compared to 1990 emissions. The United States has accepted a target of 7% below 1990 levels and Canada a target 6% below 1990 levels. However, because with no emission reduction actions both countries would experience significant increases by 2010, the reductions below the projected "business as usual" emissions by that year are expected to be 25 to 30%.

In the Kyoto Protocol, the GHGs of particular concern in exchanges with soils are CO₂, methane (CH₄), and nitrous oxide (N₂O). This discussion paper focuses on CO₂, by far the most important GHG influenced directly by human activities.

A. Credits for increasing agricultural sinks. Sinks are defined in the Framework Convention as processes or activities that remove a GHG from the atmosphere. They have been included as potential offsets for emissions in the Kyoto Protocol in a limited manner. Agricultural soils are specifically recognized in the list of potential sources of GHG, which Parties must identify in their 1990 base year emissions and try to reduce. Farm management

practices, especially conservation tillage, have reduced the amount of soil CO₂ emissions since 1990 in both Canada and the United States, and they will help achieve the targets. However, the only specifically identified sinks accepted in the Protocol are for land use changes and forests and those "verifiable changes in stock" due to afforestation, reforestation, and deforestation in the commitment period of 2008 to 2012 (Article 3.3).

Considerable controversy has arisen over the ambiguous wording of Article 3.3 on how forestry carbon sink offsets are to be determined. At its session in Bonn, Germany, in June 1998, the Subsidiary Body for Science and Technology Advice (SBSTA) was offered several alternative interpretations. Because this Article requires countries to provide estimates of their 1990 carbon stock, one interpretation was to measure the cumulative change in carbon stock as equal to the average stock in the 2008-2012 period minus the carbon stock in 1990. Another interpretation was to determine "the net change in emissions, as measured by changes in carbon stock from afforestation, reforestation, and deforestation activities, that may be used to offset emissions in the commitment period = carbon stock on 31 December 2012 minus carbon stock on 1 January 2008."

The SBSTA delegates adopted the latter interpretation. As critics have pointed out, this interpretation means countries could take any actions they wished in the decade up to 2008-in the extreme, cutting down their forests (releasing much CO₂) and then receiving credit for the regrowth and reforestation from January 2008 to December 2012 (within the commitment period). Whether this interpretation prevails at the formal meeting of the Conference of Parties in the future (Buenos Aires and others) remains to be seen. It is also uncertain whether this interpretation of Article 3.3 (forestry) will also apply to Article 3.4, which addresses agricultural soil sinks. If it does, it will tend to reduce incentives for immediate action on agricultural soil sinks; in addition, the short, 5-year commitment period might make the measurement of a slow but steady gain in soil carbon difficult to verify.

As noted, agricultural sinks are referred to somewhat differently from forestry sinks. Article 3.4 of the Kyoto Protocol requires that the Conference of Parties (COP) "shall at its first session or as soon as practicable thereafter decide upon modalities, rules, and guidelines as to how (carbon) removals in agricultural soils and

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land use changes shall be taken into account." Article 3.4 also asks the COP meeting in autumn 1998 (Buenos Aires) to take advice on this matter from its SBSTA and from the scientific assessments and methodologies developed by the Intergovernmental Panel on Climate Change (IPCC). In general, these guidelines would apply to the second commitment period (after 2008-2012), but "A Party may choose to apply a decision ... [on this matter] for its first commitment period ... provided the activities to achieve the increased sinks have taken place since 1990." Thus, a key to gaining international acceptance of carbon sequestration in agricultural soils is to have (a) a confident projection of the potential, nationally and internationally, and (b) an agreed methodology for determining "verifiable changes in stock."

B. Agricultural productivity. Increasing soil organic matter (SOM) is widely recognized as a means to increase agricultural production. Principal processes of carbon sequestration in soil include humification of organic materials, aggregation by formation of organomineral complexes, deep placement of organic matter beneath the plow zone, deep rooting, and calcification. In contrast, leading causes of decline in SOM content include different soil degradative processes (e.g., erosion, compaction, decline in soil structure, mineralization, or oxidation of humic substances). These soil degradation processes are set-in-motion by anthropogenic activities that include plowing, biomass burning, drainage of wetlands, improper grazing practices, and mining of soil fertility by low productivity subsistence agricultural practices.

The SOM content is closely linked with soil quality and soil productivity. The objective of judicious soil management practices is to enhance soil quality through improvement of SOM content and to thereby increase agricultural productivity. The SOM content can be enhanced by adding biomass to the soil and curtailing or mitigating soil degradative processes (see Section 3).

I. Carbon in agricultural soils

A. Past carbon losses

1. A global perspective

World soils constitute a principal carbon pool of 1,500 to 2,000 Pg (1 Pg =

petagram = 1 billion metric ton) in soil organic carbon (SOC) and 800 to 1,000 Pg as soil inorganic carbon (SIC) or carbonate carbon (Post et al. 1982, Eswaran et al. 1993). The SOC content is generally high in virgin soils under grass or forest vegetation. Conversion of grass and forest land to cropland and pastures leads to losses of SOC. Grassland and forest soils tend to lose from 20 to 50% of the original SOC content in the zone of cultivation within 40 to 50 years after land use change (3, 4). Historical losses of SOC have been accentuated by low production levels, intensive tillage, inadequate use of fertilizers and organic amendments, removal of crop residue and biomass burning, and lack of soil protection against erosion and other degradative processes (Cole et al. 1993, Lal 1995).

Estimates of historic loss of SOC from the cultivated soils of the world (croplands) range from 41 Pg (Houghton and Skole 1990) to 55 Pg (Cole 1996). These estimates of historical losses of SOC provide a reference level for the potential of world soils to recover and sequester carbon through improved management. Assuming recovery of 50% of the historic soil loss, the carbon sequestration potential of world cropland over the next 50 to 100 years may be on the order of 20 to 30 Pg (Cole 1996). This equals 7 to 11% of emissions from fossil fuel combustion at 1990 levels, over 50 years.

2. North America. Soils of North America account for about 22% of the terrestrial carbon pool. The total SOC pool to a depth of 1 meter is 267 Pg for North America, 52 Pg for the United States (contiguous 48 states), 13.5 Pg for Alaska, 190 Pg for Canada, and 11 Pg for Mexico (Waltman et al. 1997). Other estimates of the SOC pool of the 48 contiguous America states are on the order of 60 to 80 Pg. (Keim 1994). The cropland area in the United States is about 170 million ha (Mha), or about 19% of the total land area (Kellogg et al. 1994). It is estimated that the historic loss of SOC from U.S. cropland may be as much as 5 Pg (Lal et al. 1998a). The improved cropland area in Canada is 45 Mha (Food and Agriculture Organization 1995), with a SOC pool of about 6 Pg to a depth of 1 meter (excluding pastureland). The historic loss of SOC from cropland in Canada may be about 1 Pg. Therefore, absolute potential of carbon sequestration with improved management of cropland in the United States and Canada is about 5.5 Pg, if the losses could be fully recovered (see Section 3.2). With appropriate

measures, a significant portion of this amount may be realized over the next 20 to 30 years.

B. Current Rates of Soil Carbon Change. Much of the carbon loss from agricultural soils occurs during the first decade after cultivation. With time, the rates of carbon loss have abated, because of both depletion of the readily decomposable carbon pools and gradual improvement in soil management practices. Consequently, most agricultural soils in the United States and Canada are now almost neutral with respect to emissions; they are neither large sources nor significant sinks of CO_2 . For example, computer simulations (Smith et al. 1997a) suggest that, on average, carbon loss from agricultural soils in Canada was only about 40 kg/ha/yr in 1990 and that rates of loss are declining. In a similar evaluation of soils in the central United States (Donigan et al. 1997), it was concluded that carbon losses had diminished and that soils are now beginning to accumulate carbon again. These findings, along with others from direct soil analyses, suggest the potential for the reversal of historical C trends (i.e., the transformation of soils from a source to a significant sink for atmospheric CO_2).

II. Potential for carbon sequestration

A. Methods of increasing soil carbon. Changes in soil carbon content reflect the net result of carbon input (via plant litter) and carbon loss (via decomposition). To elicit a gain in carbon storage, therefore, a new management practice must (a) increase the amount of carbon entering the soil as plant residues or (b) suppress the rate of soil carbon decomposition. The former is a function of the net primary production (i.e., plant yield) and the proportion of the plant yield that is eventually returned to the soil in the form of plant litter or crop residues. The rate of decomposition is controlled by soil conditions (e.g., moisture, temperature, and oxygen sufficiency), composition of the organic material, placement of the material within the soil profile, and the degree of physical protection (e.g., within soil aggregates).

Soil carbon storage can also change through erosion, which redistributes carbon across the landscape. Thus, some parts of the landscapes may lose carbon while others may gain carbon. Aggregate breakdown leads to rapid mineralization of carbon previously encapsulated within the aggregates. Because some of the eroded material is deposited elsewhere on the

landscape or in water systems, not all the carbon lost by erosion can be considered a net contribution to atmospheric CO₂. For the same reason, soil carbon gains resulting from a practice that reduces erosion cannot be entirely equated to removal of atmospheric CO₂.

On cultivated land

Numerous strategies for increasing carbon in cultivated soils have been identified (Table 1). These can be broadly classified into four main approaches: (i) reduction in tillage intensity; (ii) intensification of cropping systems; (iii) adoption of yield-promoting practices, including improved nutrient amendment; and (iv) reestablishment of permanent perennial vegetation.

Tillage can promote soil carbon loss by several mechanisms: It disrupts soil aggregates, which protect SOM from decomposition; it may stimulate microbial activity through enhanced aeration; and it mixes fresh residues into the soil, where conditions for decomposition are often more favorable than on the surface. Furthermore, tillage can leave soils more prone to erosion, resulting in further losses of soil carbon. As a result, adoption of practices with reduced tillage can result in significant accumulation of soil carbon (Lal et al. 1998a, Paustian et al. 1997b). This accrual of soil carbon can be further enhanced if reduced tillage also increases yield (e.g., through improved moisture retention). With recent advances in seeding equipment and weed control, reduced- and no-tillage systems are now practicable in many regions and cropping systems.

Many cropping systems can be intensified by increasing the duration of photosynthetic activity. For example, greater use of perennial forages often enhances soil carbon, because these crops have extended periods of active growth and allocate greater proportions of their carbon below ground (Paustian et al. 1997a). Other opportunities for intensification of cropping systems include the use of winter cover crops (Kuo et al. 1997) and the elimination of summer fallow. Intensification of cropping systems not only increases the amount of carbon entering the soil, it may suppress decomposition rates by cooling the soil through shading and by drying the soil.

Application of nutritive amendments, including commercial fertilizers and organic amendments, favors soil carbon by increasing yields and, consequently, the amount of residues returned to the soil

(Paustian et al. 1997b). Addition of organic amendments like livestock manure also promotes soil carbon by adding carbon directly, although this carbon is merely a recycling of crop carbon and does not necessarily represent a new input. Other agronomic options that may furnish higher yields include improved crop varieties, better pest control, more efficient fertilizer practices, and improved water management (including irrigation). These higher yields will translate into higher soil carbon contents, provided the higher residue amounts are returned to the soil.

2. *On revegetated or "set-aside" land.* Perhaps the most effective way of restoring soil carbon content on land that has been cultivated is to reestablish and maintain perennial vegetation. Soil carbon increases have been observed for both managed (e.g., pasture establishment) and unmanaged (e.g., old-field successions) conversions of cultivated lands. These increases in soil carbon can be attributed to the absence of physical disturbance due to tillage, increased carbon inputs resulting from less removal of carbon in harvested crops, and greater allocation of carbon below ground, particularly with perennial grasses (Paustian et al. 1997b). Rates of accumulation vary, depending on climate and soil conditions. For example, mesic environments with high productivity show greater rates of accumulation (Jastrow 1996) than less productive semi-arid grasslands (Burke et al. 1995, Dormaar and Smoliak 1985).

Although revegetation of cultivated lands with grasses or trees may achieve the highest carbon gain per unit of land area, it requires removing that land from annual crop production and does not therefore apply on as wide a scale as do some of the other carbon sequestration options.

3. *On pastures and rangeland.* Management factors that can impact soil carbon levels on grasslands in general include grazing management, use of fire, species selection, and use of production inputs (e.g., fertilizer, irrigation). In general, soils that have the highest capacity for increased carbon levels are those that have been depleted of carbon in the past due to poor management or having been cultivated and used for annual crop production.

On intensively managed grasslands (e.g., pastures), where productivity and management inputs are relatively high, there are opportunities for increasing soil carbon. Good pasture management has the potential to increase soil carbon through improved practices such as rotational grazing and application of fertilizers

(Nyborg et al. 1997). Other potential opportunities for increasing SOC include irrigation and reseeding with improved species or varieties (Table 1).

On extensively managed grasslands (e.g., rangeland), grazing intensity and frequency are the main management variables that can affect soil carbon levels. Grazing can influence plant species composition, net primary productivity, above-ground and below-ground allocation in plants, and nutrient cycling pathways (Milchunas and Lauenroth 1993, Burke et al. 1997). The general conclusions that can be drawn from these and other studies (Bauer et al. 1987, Frank et al. 1995, Manley et al. 1995) is that where the vegetation cover and production capacity of grasslands are not adversely affected by grazing, there is little change in SOM. However, in areas where overgrazing has seriously degraded vegetation cover and primary production, soil carbon will be lower due to increased erosion losses and reduced carbon inputs. In these situations, improved management to restore productivity levels could lead to concomitant increases in soil carbon.

4. *On degraded land.* Soil quality, its agronomic productivity and environmental moderating capacity (Lal 1997), relies heavily on SOC content. Drastic reduction in SOC content leads to decline in soil quality and vice versa. Soil degradation is a more severe problem in arable land than in rangeland and forest/woodland. On a global scale, the problem of soil (and environmental) degradation is more severe in the tropics than in temperate regions, in dry rather than moist ecoregions, and warm rather than cold climates. Available statistics on soil degradation (Oldeman 1994) are vague and subjective, especially for the tropics and subtropics. Of a total estimated area of about 2 billion ha of degraded soils worldwide, as much as 75% may be in the tropics. Total land area prone to soil degradation in North America is estimated at 96 Mha (Oldeman 1994), of which 70 Mha may be in the United States and Canada (Wall et al. 1995, Wicherek and Laverdiere 1993). Of the 70 Mha, degraded cropland in the United States and Canada may be 53 Mha (U.S. Department of Agriculture 1995).

Soil degradation may be due to several processes, including accelerated soil erosion, salinization, drastic disturbance by mining and urban activities, overstocking and grazing land, decline in soil structure by vehicular traffic, and soil contamination by industrial pollutants (Lal 1997).

Restoration of degraded soils involves

reversion to natural vegetation cover, establishment of rapidly growing perennials and annuals, and application of inorganic fertilizers and organic amendments. If SOC content is severely depleted but the soil's resilience characteristics are functional, restorative measures can improve SOC content. The rate of carbon sequestration through soil restoration depends on antecedent properties, restorative measures, ecoregional characteristics, and the initial SOC pool under natural conditions.

Total potential carbon storage in agricultural soils

While there is strong evidence that agricultural soils can become a net sink for CO₂, the eventual size of that potential sink has a range of uncertainty. Soils cannot accrue carbon indefinitely. Based on ecological principles (Odum 1969), soil carbon eventually reaches some equilibrium value that cannot be exceeded easily. The maximum potential gain, therefore, is the difference between the current carbon status and that eventual equilibrium value.

A simple way to estimate potential carbon gain is to predict the proportion of previously lost carbon that can be recovered with improved management. For arable cropland, the eventual equilibrium carbon content will usually be less than the precultivation content. Several constraints may prevent soil carbon from approaching the precultivation values:

1. Agricultural ecosystems are designed to maximize exported (harvested) carbon; consequently, amounts of carbon returned to the soil are often less than those in "native" systems;

2. Because of loss in quality through erosion, salinization, or other degradative processes, some soils can no longer be returned to the level of productivity achieved before cultivation; and

3. Although the new, emerging soil management practices are relatively nondisruptive (e.g., no-tillage systems), they still invariably disturb the soil through seeding and other agronomic practices. Many of these constraints, however, can be at least partially offset by the addition of inputs like fertilizers, organic amendments, and irrigation water.

An initial estimate of potential carbon gain on agricultural land can be obtained by assuming that improved management practices can recover about 50% of the carbon previously lost (Cole 1996). Based on this assumption and the estimates of previous carbon loss (Section 2. 1), the

potential gain of carbon in Canada and United States amounts to about 3 Pg. This estimate, however, assumes widespread adoption of the best possible carbon-conserving practices on the entire area. Clearly, economic, social, and other constraints limit adoption rates. Thus, the achievable carbon gain will be less than the potential value of 3 Pg. Furthermore, it may take as long as a century or more to attain maximum carbon storage.

C. Potential rates of carbon gain over the next two decades

1. *On cultivated land.* Depending on the amount of potential carbon gain, it may take about a century for soils to reach their maximum carbon content. Rates of carbon accrual, however, are usually highest in the first two decades after the management change, then rapidly diminish.

The rate of carbon gain after adoption of an improved practice varies among soils. For example, results were summarized from 27 studies, primarily in the United States, which measured the increase in soil carbon under no-till relative to conventional tillage (usually moldboard plowing) after a period of 5 to 20 years (Paustian et al. 1997b). Carbon gains under no-till ranged from - 4 to +10 Mg/ha (mean = + 3 Mg/ha). A similar range has been reported in a review of 17 Canadian comparisons (Janzen et al. 1997) and a more recent review of 26 long-term comparisons in the United States and Canada (Elliot et al. unpublished data). The variation of the response may reflect several factors:

- a. *The initial carbon status of the soil.* Soils that have been depleted of carbon by previous management may have much higher potential for carbon gain than soils that have always been well managed.

- b. *Climatic region.* The rate of carbon accrual may be much higher in environments with high productivity. For example, rates of carbon gain may be limited in environments where productivity is limited by cool temperatures or aridity. Consequently, rates of accumulation in Canada and in semiarid regions of the United States may be less than those in higher-yield regions.

- c. *Other agronomic variables.* The amount of carbon gain in response to no-till may depend on the complement of other practices, like fertilizer application and crop sequence.

Despite the variability of response, the average rate of carbon accumulation can probably be estimated with reasonable accuracy from the long-term data as about 0.3 Mg/ha/year. To estimate the potential

rate of carbon accumulation during the first decades to 2020, we make the following two assumptions:

- a. The best possible carbon-conserving practices are adopted on all nondegraded cultivated land in the United States and Canada by the year 2000. In most cases, these practices will include reduced tillage in conjunction with improved crop rotations, fertilization techniques, and other favorable practices, as appropriate for the given soil and climate (Table 1).

- b. During the first two decades after adoption, the rate of carbon gain in response to these practices averages 0.2 Mg/ha/year in soils where productivity is constrained by cool temperatures or aridity and 0.4 Mg/ha/year in other soils. Based on these assumptions, the gain of carbon in cultivated soils would be nearly 765 Tg C over two decades (see Table 2).

2. *On revegetated or "set-aside" land.* Conversion of previously cultivated land to perennial grassland usually results in high rates of soil carbon gain. The U.S. Conservation Reserve Program (CRP), started in 1985 and currently including about 14 Mha of land planted to perennial grasses or trees, provides an estimate of these rates of carbon accrual. Analysis of soils on CRP lands in the western and central U.S. shows rates of <0.10 to 0.40 Mg/ha/year as soil organic matter and 0.25 to 1.35 Mg/ha/year of total below-ground C, including roots (Paustian et al. 1995, Gomez 1995). These rates of accrual, however, will diminish with time, particularly because a large part of the initial carbon gain may occur as roots and other plant litter.

Based on these estimates and other values in the literature (Paustian et al. 1997b), we assume that a typical rate of carbon gain upon conversion to perennial grasses averages about 0.8 Mg/ha/year in the first decade after conversion. Most CRP lands and similar lands in Canada have now been under grass for about a decade, so further carbon gains over the second decade may be only about 75% of this figure (Table 2). If a portion of these lands is returned to annual crop production after the contract period expires, however, much of the accumulated carbon may be lost.

A variety of other, potentially more permanent, grass conversions are being adopted for soil conservation and water quality purposes. These include practices such as field borders, filter strips, grassed waterways, shelterbelts, and terrace walls, which consist of areas of perennial grass, legumes, or trees in close association with

annual cropland. Because these areas are usually actively managed, it is reasonable to suppose that carbon accumulation rates would be equal to or higher than CRP conversions. Currently there are about 0.9 Mha in such conservation uses, most of which has been established over the past 10 to 20 years. The goal of the U.S. Department of Agriculture's Natural Resources Conservation Service is to increase the total area to 2.8 Mha by the year 2000.

3. *On pastures and rangeland.* Intensively managed pastures have potential for further carbon gains through the use of improved grazing regimes, improved species, fertilization practices, and irrigation management, although there are few comprehensive studies of the amount of gain. For our estimates of carbon gain during the next two decades, we assume that adoption of best management practices on these pastures would elicit a carbon gain of 0.2 Mg/ha/year, resulting in about 11 Tg C per year over the next two decades, for a total of about 220 Tg C.

Most extensively managed rangelands and long-term (i.e., >50 years) pastures are probably near equilibrium with respect to carbon and, consequently, will not be a significant sink for carbon without some additional inputs, such as fertilizer. For these estimates of potential carbon gain, we assume no further gain of carbon in these soils (Table 2).

4. *Degraded land.* Severely eroding land erodes at a rate exceeding four times the tolerable soil loss (rate in excess of 44.2 Mg/ha/yr). Eroding at an excessive rate for a long time depletes SOC content, lowers soil quality, and reduces biomass production. Cropland subjected to moderate and severe levels of wind and water erosion is 38.5 Mha in the United States (Gomez 1995). However, a part of the highly erodible land is already under CRP (see section 3.3.2). Therefore, the additional land area "at risk" could be put under restoration in the United States is about 28.6 Mha. In Canada, the land area prone to severe water erosion is about 5.4 Mha and the area prone to severe wind erosion is about 2.1 Mha. Of this, perhaps 20% may be severely eroded already; hence, the land area degraded by erosion in Canada may be about 1.5 Mha (Wall et al. 1995, Wicherek and Laverdiere 1993). Assuming that the carbon sequestration potential of this land is 0.5 Mg/ha/yr, the total carbon sequestration through restoration of eroded cropland is about 15 Tg C per year (Table 2).

The United States and Canada have

Table 1. Management practices that can increase soil carbon (partial list)

Management Practice (Per Unit Area)*	Feasibility*	Relative Carbon Gain
Cultivated Land		
Adoption of reduced- or no-till	H	M (large area)
Use of winter cover crops	M	L
Improved crop nutrition & yield enhancement	H	L
Elimination of summer fallow	M	M
Use of forages in rotation	M	M
Use of improved varieties	H	M
Use of organic amendments	M	M
Irrigation	L	H
Revegetated or Set-Aside Land		
Reestablishment of perennial grasses	L	H
Soil/water conservation measures (e.g., grassed waterways, shelterbelts)	H	H
Reversion to woodland	L	H
Pastureland		
Improved grazing regime	M	M
Fertilizer application	H	M
Use of improved species/varieties	M	M
Irrigation	L	M
Rangeland		
Improved grazing regime	L	L
Degraded Land		
Reversion to native vegetation	M	H
Establishment of fast-growing crops	M	H
Application of fertilizers	H	M
Application of organic amendments	M	H
Drainage/leaching of saline soils	L	L

* H=high
M=medium
L=low

several other forms of degraded soils: salt-affected soils, abandoned mine lands, and other drastically disturbed lands. Land area in the United States at high risk of salinization is estimated at 20 Mha (U.S. Department of Agriculture 1995), and the area of saline soil in Canada is estimated at about 2.2 million ha (Dumanski et al. 1986). Reclamation of salt-affected soils may lead to carbon sequestration at the rate of 0.1 Mg/ha/yr. The total area of salt-affected soils in the United States and Canada is 22.2 Mha. Therefore, the potential for carbon sequestration through restoration of salt-affected soils in the United States and Canada is about 2.2 Tg/yr for about 20 years. The land area under abandoned minelands is 0.6 Mha in the United States and 0.1 Mha in Canada. The rate of carbon sequestration in these highly disturbed soils may be about 1 Mg/ha/yr. Therefore, the carbon sequestration potential of restoring drastically disturbed lands is about 0.7 Tg C/yr.

D. Summary of potential and comparison to total emissions. Based on the above estimates for sequestering carbon through improved practices, the agricultural soils and degraded lands of the United States

and Canada could gain about 1,700 Tg (1.7 Pg) carbon within two decades (Table 2). However, this estimate assumes that the best possible practices in Table 1 are adopted on all identified lands at the beginning of the two decades, an assumption that clearly overestimates achievable gains. The actual adoption of these practices in the future is uncertain, depending on policies adopted and changing economic and political factors. Another important factor is the time of adoption. Because reduced tillage and other practices are already in use on a portion of these lands, the total further carbon gain may be somewhat lower than the estimates in Table 2.

The values in Table 2 provide an estimate of the maximum potential carbon gains given a concerted, widespread effort to sequester carbon immediately. For an estimate of carbon gain if no effective programs or incentives are introduced to promote carbon-conserving measures, we assume adoption of carbon-conserving practices on 20% of the lands in the year 2000 and an additional 1% every year thereafter, resulting in adoption on 39% of lands by 2019. Based on these assump-

Table 2. Estimates of Potential Carbon Gain in Agricultural Soils within Two Decades (Assumption: The best possible carbon-conserving practices adopted on all agricultural lands in the United States and Canada.)

	Area (million hectares) Canada ¹ U.S. ²		Rate of C Gain per Hectare (Mg C/ha/year)	Average Annual C Gain Next Two Decades (Tg C/year)	Estimated Total C Gain Next Two Decades (Tg C)
Nondegraded Cropland					
Cool or dry climate	37.0	33.9	0.2	14.2	284
Favorable climate	0.0	60.1	0.4	24.0	481
"Set-Aside" Land					
Grassland (existing) ³	0.5	12.8	0.6 ⁵	8.0	160
Grassland (new) ⁴	0.5	8.7	0.8	7.4	147
Soil/water conservation measures ⁶	n/a ⁴	2.8	0.8	2.2	45
Woodland	n/a ⁴	1.0	0.4	0.4	8
Grasslands					
Intensive	4.3	51.0	0.2	11.1	221
Extensive	15.1	162.0	0.0	0.0	0
Degraded Soil					
Eroded (cropland)	1.5	28.6	0.5	15.1	301
Saline	2.2	20.0	0.1	2.2	44
Disturbed	0.1	0.6	1.0	0.7	111
Total				85	1,705

Abbreviations:

C = carbon
ha = hectares

Mg = megagram = 10^6 g
Tg = teragram = 10^{12} g

Note. See Section 3.4 for modification of maximum potential total to allow for gradual implementation of measures and for comparisons with total emissions.

¹ Sources: Canada Census (1996) data were used for estimates of cultivated soils (41.2 million ha), extensive grasslands (15.6 million ha), and intensive grasslands (tame or seeded pasture; 4.3 million ha). Area of eroded soils was estimated by assuming that 20% of the cultivated soils with "severe inherent (bare soil) risk" of water or wind erosion (Wall et al. 1995) are currently degraded. The estimate of saline areas is from Dumanski et al. (1986). "Existing grassland" under "set-aside" lands is an estimate of current area under the Permanent Cover Program (PCP); "new" grassland estimate arbitrarily assumes a doubling of this area. "Nondegraded cropland" was calculated by subtracting eroded, saline, and "new" grassland areas from total cultivated area. All this area was assumed to be under "cool or dry climate." The area of "extensive grassland" was corrected for "existing set-aside" grassland ($15.6 - 0.5 = 15.1$ million ha). Area of disturbed land was not subtracted from any category.

² Source: USDA-National Resource Inventory for 1992. Total cropland area of 168.5 Mha was subdivided into nondegraded cropland, set-aside lands, and degraded cropland soils. After subtracting the area represented by degraded soils and set-aside land, remaining cropland ("nondegraded") was subdivided into climate types according to major land resource area (MLRA) designations.

³ Total area of potential set-aside lands for the United States is based on an estimate of 15% of total cropland potentially available as surplus (Cole 1996). For the United States, existing "set-aside" lands are mainly those in the Conservation Reserve program; estimate for new "set-aside" area was derived by subtracting the area in CRP (including tree planted) in 1992 plus the area projected for other conservation measures from the total potential set-aside area.

⁴ Assumes that the existing grassland from previous conversions, many of which have been in place for about a decade, accumulate carbon at 0.75 the rate of new grassland.

⁵ Includes practices like grassed waterways, field borders, filter strips, terrace walls, and shelterbelts—U.S. estimates are based on an NRCS goal of 2 million miles (2.8 million ha) of conservation buffers by 2000.

⁶ Indicates that data on areas are not available and, for these calculations, are assumed to be negligible.

tions, agricultural soils in the United States and Canada would gain about 500 Tg C over 20 years. On the other hand, with a widespread, concerted effort to increase the use of carbon-conserving practices, potential carbon gains are much higher. Assume again that adoption is at 20% in 2000, but with incentives we might assume a 5% increase in adoption every year thereafter, leading to 70% adoption by 2010 and full adoption by 2016. In this scenario, the estimated carbon gain in soils over two decades would be 1,100 Tg.

CO₂ emissions from all sources, expressed as C, were 126 Tg for Canada and 1350 Tg for the United States in 1990,

for a total of 1,476 Tg. Therefore, the estimate of 1.1 Pg C above (assuming gradual but vigorous programs for implementation of measures over the coming two decades), represents 3% to 4% of total North American emissions over this period at 1990 rates. However, this potential mitigation through soil carbon sequestration represents a much higher percentage of the emission reduction targets for the United States and Canada under the Kyoto Protocol. If 70% of full potential were reached during the commitment period 2008-2012, this would average 60 Tg C per year over this period. Assuming a 20% increase in emissions, without regulation, between 1990 and 2010, the

combined United States and Canadian target for emission reductions is about 400 Tg C per year. Thus, with a concerted effort soil carbon sequestration may achieve about 15% of the total annual mitigation targets for the United States and Canada under the Kyoto Protocol.

III. Techniques for estimating carbon sequestration potential

A. Direct Measurements. The most direct means of determining soil carbon sequestration is to measure, over time, sequential changes in soil carbon. Such measurements are complicated by the spatial and temporal heterogeneity of soil

carbon contents and its slow relative rate of change. Soil carbon can exhibit significant field-scale variability due to spatially varying topography and parent material or past differences in vegetation or management history. Even in seemingly 'uniform' fields, soil carbon contents can vary by as much as 100% (Elliott 1994). In addition, the seasonality of plant growth and decomposition processes can cause temporal variability in carbon fractions, in roots, plant litter and microbial biomass. Finally, short-term (i.e., annual) changes in total carbon can be difficult or impossible to detect against the large "background" of carbon already in the soil.

Many of these problems can be overcome through the use of well-designed sampling and analysis procedures that minimize effects of spatial and temporal variability and standardize sample preparation. Measurements of specific soil carbon fractions may be useful as early indicators of change (Lal 1997), although it may still be necessary for monitoring periods of several years to verify changes in total soil carbon.

Most data on soil carbon changes in agricultural soils are derived from long-term field experiments (Paul et al. 1997). Where treatments have been properly randomized, significant differences in soil carbon as a function of different agricultural management practices can be statistically inferred.

In general, direct sampling is of greatest value at a farm or small scale level but can be of some assistance in verifying national level estimates.

B. Modeling. Mathematical modeling of soil carbon dynamics is relatively well developed, particularly for agricultural soils. Models have been used to investigate how SOM varies across regions and landscapes as a function of climate, vegetation, topography, soils, and other environmental factors. Soil carbon changes in response to changes in management practices (e.g., tillage, crop type and rotation, fertilization, manure application) have been modeled extensively.

The most widely used simulation models conceptualize SOM as being composed of 3 to 4 fractions, which vary in physical and chemical properties affecting turnover rates (35). Crop residues are similarly subdivided into 2 to 3 fractions varying in decomposability. The environmental factors controlling SOM in most models include soil temperature and moisture, soil aeration or drainage class, soil texture, and mineralogy. The rate of organic matter input as crop residues, ma-

nure, sludge, or other amendments is a major determinant of soil carbon levels. Some models simulate crop growth and residue inputs directly, while others require that organic matter addition rates be specified as inputs to the model. The IPCC guidelines address empirical modeling. The use of SOM models range from the field level (Jenkinson et al. 1987) to regional (Parton et al. 1987) and global applications (King et al. 1996).

C. Confidence in models and quantification/verification methods. There appears to be reasonable consensus that state-of-the-art SOM models include the essential factors controlling soil carbon. Many soil carbon models have been quite successful in simulating carbon dynamics at the field scale, but they generally require some degree of site-specific calibration. For example, a control treatment in a long-term experiment could be used to calibrate model inputs or initial conditions that are then used to independently simulate other treatments in the field experiment (Smith et al. 1997b). Such procedures can build confidence in the internal consistency of the model but do not constitute a strict validation test. Some degree of calibration may be unavoidable due to uncertainties about past management histories and levels of organic matter input. However, approaches using simulation models in conjunction with regional networks of long-term experiments (Paustian et al. 1995) and field-level monitoring points for model verification are promising.

A framework for quantification and verification is proposed which integrates (1) data from long-term field experiments; (2) spatial databases of climate, soils, land use, and management; (3) quantitative models to assess soil carbon change; (4) process studies to support model refinement; and (5) on-farm relocatable sampling points for monitoring purposes. Models, based on the best available knowledge from basic research, are used to estimate rates of change for soil carbon as a function of climate, soil, land use, and management conditions. To apply at regional and national scales, these models must be validated for a wide range of environmental and management conditions using spatially distributed networks of long-term experiments. Such site networks have been established both in the United States and Canada (Paul et al. 1997) and globally (Smith et al. 1996).

Existing regional and national databases (i.e., on land use, soils, climate) provide the inputs necessary to drive the model for

combinations of climate, soil, and management conditions. They also provide the means to scale model results up to regional and national levels. Remotely sensed data as well as conventional agricultural statistics (e.g., USDA's National Resource Inventory, Conservation Tillage Information Center) provide information on changes in management and the adoption of carbon sequestering practices. Finally, the establishment of on-farm relocatable sample points provides an independent means of verifying model estimates of soil carbon changes through direct measurements and statistical comparisons. A pilot project that includes a network of such on-farm monitoring points has been established for Saskatchewan.

Such a framework, which combines modeling and empirical methods, could provide a reliable and low-cost means of quantifying and verifying changes in soil carbon stocks. Studies utilizing this type of approach, at a regional basis, have been recently initiated in both the United States and Canada, as well as in Europe.

UNITS AND ABBREVIATIONS

- 1 unit carbon, or C, converts to 3.67 units carbon dioxide (CO₂)
- 1 tonne (metric ton) = 1.12 short ton
- 1 million metric tons (abbrev) = mt (or MM'T)
- 1 hectare (ha) = 2.471 acres (a) = 10,000 square metres (M)
- Mha = million ha. or mega.ha
- 1 square metre (M) = 10.764 square feet (ft)
- 1 square kilometre (km²) = 100 hectares (ha) 0.386 square miles (Mi²)
- parts per million by volume (abbrev) = ppmv
- parts per billion by volume (abbrev) = ppbv
- kilo-10³ (thousand), e.g., kilogram (Kg)
- 1 Kg = 2.205 pounds (lb)
- mega-10⁶ (million), e.g., megagram (Mg)
- giga-10⁹ (billion), e.g., gigagram (Gg)
- tera-10¹² (trillion), e.g., teragram (Tg)
- 1 Tg = 1 mt (million metric tons)
- peta-10¹⁵ (quadrillion), e.g., petagram (Pg)

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Einstein condensate gave rise to superradiance based on coherent external motion. The extremely low threshold in light intensity ($\sim 1 \text{ mW/cm}^2$ for our conditions) should be taken into account in BEC experiments that use optical probing and manipulation with off-resonant light. The simultaneous superradiant emission of light and atoms emphasizes the symmetry between atom lasers and optical lasers.

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13. In (3), the recoiling atoms propagated perpendicular to the long axis of the condensate. The “finite size” contribution to the Doppler broadening was therefore twice that of the present geometry.
14. Elastic collisions at a maximum rate of $\sim 2 \text{ kHz}$ do not contribute substantially to $L_\parallel$, although they reduce the number of atoms in the superradiant peak by $\sim 50\%$.
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The U.S. Carbon Budget: Contributions from Land-Use Change

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The rates at which lands in the United States were cleared for agriculture, abandoned, harvested for wood, and burned were reconstructed from historical data for the period 1700–1990 and used in a terrestrial carbon model to calculate annual changes in the amount of carbon stored in terrestrial ecosystems, including wood products. Changes in land use released 27 ± 6 petagrams of carbon to the atmosphere before 1945 and accumulated 2 ± 2 petagrams of carbon after 1945, largely as a result of fire suppression and forest growth on abandoned farmlands. During the 1980s, the net flux of carbon attributable to land management offset 10 to 30 percent of U.S. fossil fuel emissions.

The rate at which carbon is accumulating in terrestrial ecosystems in the United States is uncertain, as are the mechanisms responsible for the current sink. Estimates based on measured changes in wood volumes (forest inventories) (1–3) range between 0.079 and 0.280 petagrams of carbon per year (Pg C year^{-1}). An estimate, based on atmospheric and oceanic data and models, and including southern Canada, calculated a sink of $1.7 \pm 0.5 \text{ Pg C year}^{-1}$ (4). Neither of these approaches identifies the mechanisms responsible for the sink (5). In contrast, although the changes in carbon associated with land-use change do not define the total net flux of carbon between land and atmosphere, they represent the portion of the flux that can be attributed to direct human activity, and it is this portion that is addressed by the United Nations Framework Convention on Climate Change and by the Kyoto Protocol. In this report, we estimate the annual flux of carbon in the United States attributable to changes in land use.

Our approach is based on two types of information: rates of land-use change and changes per hectare in carbon that follow a change in land use. We considered the conversion of natural ecosystems to croplands (cultivated) and pastures (not cultivated), the abandonment of croplands and pastures, harvest of industrial wood and fuel wood, and fire management, that is, the area annually

burned by wildfires. Rates of agricultural clearing and abandonment and rates of wood harvest were obtained directly from the U.S. Department of Agriculture (USDA) for the period since 1945 (6) and largely from the U.S. Bureau of Census (7) for the period between 1700 and 1945. Areas burned each year were obtained from wildfire statistics of the U.S. Forest Service (8) for the period after 1930 and from pre-European burning rates (9) modified by settlement and logging practices for the years 1700–1930 (10). A more detailed description of the data, sources, and assumptions can be found elsewhere (11, 12).

We divided the United States into seven geographic regions (each region including two to five natural ecosystems) for a total of 13 different ecosystems, not including croplands and pastures. The areas and carbon stocks of ecosystems in 1700 were determined from both natural areas (13) and current ecosystems (14). The fractions of vegetation left alive, killed, and burned as a result of human activity and fire were defined for each type of land use and ecosystem. The efficiency of industrial wood harvest increased through time, so that more wood was removed per hectare and less left as slash (dead vegetation) (15, 16). Rates of forest growth after harvest, fire, and agricultural abandonment and rates of decay of organic matter for each ecosystem were obtained from the ecological literature (17). Changes in soil carbon included only the losses that resulted from cultivation and the reaccumulations that followed abandonment of cultivated land. These per hectare rates of carbon loss and accumulation after changes in land

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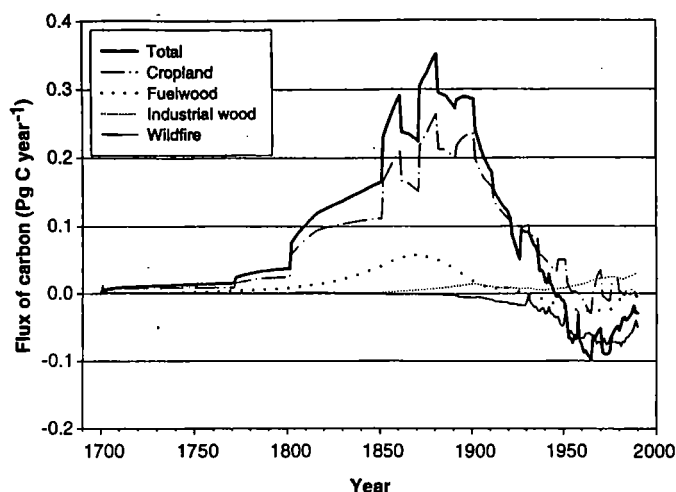


Fig. 1 (Left). Annual net sources and sinks of carbon resulting from different types of land use in the United States.

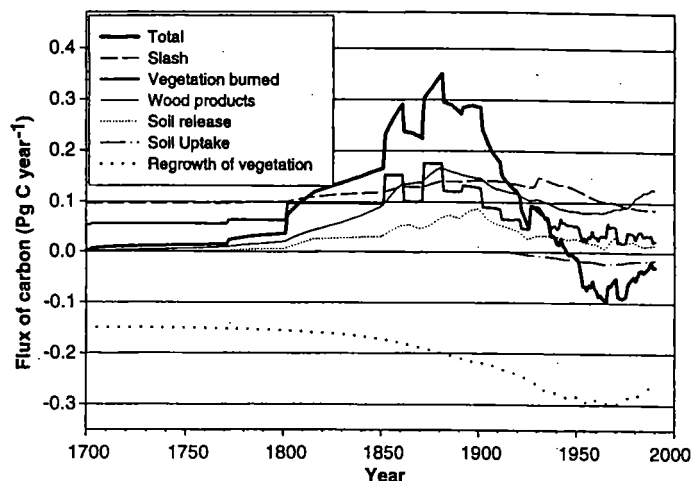


Fig. 2 (Right). Annual losses and accumulations of carbon in different terrestrial pools as a result of land management in the United States.

use were used in a bookkeeping model (18) to calculate annual changes in carbon for each type of ecosystem, land use, and region. The areas of forest burned each year, together with the total area of forest in each region and the rate of forest growth, constrained the average biomass that could be burned per hectare in a region's forests (19).

According to our analysis, changes in land use released about 25 Pg C to the atmosphere over the period 1700–1990, largely from the conversion of forests to agricultural lands and from cultivation of prairie soils (Fig. 1). The net release, overall, included a net uptake of 2.4 Pg C after 1945 as both the area and biomass of forests increased in response to fire suppression, reduced harvest of fuel wood, and the abandonment of farms. It also included an uptake in eastern forests, largely offset by releases of carbon from western regions where rates of industrial wood harvest increased.

The net flux resulted from accumulations of carbon in regrowing vegetation and, to a lesser extent, soils and from releases of carbon from burning and decay (Fig. 2). Before European settlement, fires accounted for the largest sources (immediate burning and delayed decay) and sinks of carbon, although the net flux from fire was nearly zero as long as rates of burning were about constant. As wood harvest and agricultural clearing increased in the 18th century, emissions from fire, soil, and wood products increased, but annual accumulations also increased as the areas of forests recovering from fire and harvesting increased. Replacement of wood fuels with fossil fuels midway through the 19th century began to reduce the emissions from fuel wood harvesting, and fire suppression after 1930 further reduced the areas burned. Despite the recovery of forests in the east, increasing rates of industrial wood harvests in the west and south increased the generation

of slash and wood products and hence emissions of carbon. The largest annual accumulations of carbon occurred in the 1950s and 1960s. By the 1970s, as a result of aging (slower growing) forests and a resurgence of fuel wood use, the net flux from land-use change was close to zero.

The errors resulting from uncertainties in rates of land-use change, from aggregated estimates of biomass, growth, and decay, and from simplifying assumptions in the structure of the model may be estimated by comparing the results of successive analyses (Fig. 3). For the three analyses in which changes in land use are reasonably well documented, estimates of the long-term (1700–1990) carbon flux range between 24 and 30 Pg C. For shorter intervals, the errors are larger. The difference between our estimate that includes fire and an earlier estimate for North America that did not include fire (18) is as large as 0.2 Pg C year⁻¹ before 1900. A comparison of our estimates with and without fire shows that including fire and fire suppression changed estimates of flux by as much as 0.05 Pg C year⁻¹. Surprisingly, fire reduced the estimated emissions during the 1800s. The reduction occurred because the biomass of forests cleared for agriculture was less if fire

was included in the analysis. The errors are estimated to be less than ± 0.1 Pg C year⁻¹ in recent decades (20). The analysis that shows a large sink for carbon beginning in 1920 is based on generous assumptions about woody encroachment (21) and early fire exclusion (22). Although detailed site-specific data document these processes, the aerial extent and the historical pattern of the changes are unknown. The curve represents an upper limit for the sink strength of U.S. ecosystems.

Most other estimates of flux available for comparison pertain to the 1980s and 1990s. Our analysis for the 1980s shows an average annual accumulation of 0.037 Pg C (Fig. 4). This net uptake results from the uptake of carbon by growing vegetation (0.280 Pg C year⁻¹) and emissions from the decay of wood products (0.104 Pg C year⁻¹) and slash (0.091 Pg C year⁻¹), some of which had accumulated before 1980. The uptake of 0.280 Pg C year⁻¹ occurred on 200×10^6 ha of recovering forest and woodlands (about 65% of the U.S. forest areas). The average rate of growth (1.4 Mg C ha⁻¹ year⁻¹) was low, indicating that many of the forests and woodlands were aging and their rates of growth were declining. For comparison, net annual uptake in a 55- to 75-year-old New

Table 1. Average annual changes in the amount of carbon held in forests and wood products during the 1980s (petagrams of carbon per year). Positive values indicate an accumulation on land.

	Method		
	Forest inventory (2)	Forest inventory (3)	Land-use change (this study)
Trees and understory vegetation	0.098	0.063	0.020
Wood products (37)	-0.072	0.027	0.027
Woody debris and forest floor	0.021	0.016	-0.012
Soils (38)	0.155	0	0.002
Net accumulation	0.202	0.106	0.037

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England forest varied between 1.4 and 2.8 Mg C ha⁻¹ year⁻¹ (23).

The rate of carbon accumulation attributed to land-use change in our study is somewhat less than that determined from direct measurement of wood volumes in forests (forest inventories) (24) (Table 1). Despite the relatively high variability of estimated changes for soil carbon and wood products, the absolute differences between analyses based on forest inventories are <0.2 Pg C year⁻¹, about the error estimated for our analysis.

The approaches based on land-use change and on forest inventories are largely independent, and differences in their results may suggest the importance of management in determining the accumulation of carbon in forests (25). Carbon accumulations in our analysis are calculated by applying growth rates to forest areas previously harvested. Carbon accumulations obtained from forest inventories, on the other hand, are based on measured rates of growth, which include both recovery from earlier harvests and other factors. If CO₂ fertilization, climatic change, or N deposition were responsible for an enhanced rate of growth, for example, one would expect analyses based on forest inventories to show higher rates of growth (and a greater rate of carbon accumulation) than the analysis based on land-use change (in which rates of growth were held constant over time) (26). This difference in accumulation rates is observed. The growth attributable to recovery from previous harvests accounts for only 20 to 30% of the growth measured (Table 1). The other 70 to 80% may be attributable to other factors. Remarkably, the uptake of carbon calculated recently with a process model including variations in temperature, precipitation, and increased CO₂ accounts for the rest of the difference (0.078 Pg C year⁻¹) (27). The agreement is fortuitous given the errors associated with the estimates, but it suggests that both changes in land use and the responses of ecosystems to environmental

Table 2. Average annual emissions (+) and accumulations (–) of carbon (petagrams of carbon per year) during the 1980s from forestry and changes in land use. Changes in soil carbon are included in cultivation and abandonment of croplands. Wood products are included in the emissions from harvests.

	Emissions from burning and decay	Accumulations in recovering ecosystems	Net flux
Croplands	0.092	–0.090	0.002
Pastures	0.025	–0.025	0
Wildfires	0.081	–0.144	–0.063
Industrial harvests	0.094	–0.067	0.027
Fuel wood harvests	0.022	–0.025	–0.003
Subtotal	0.314	–0.348	–0.037
Woody encroachment			–0.122
Continued "thickening" of western pine woodlands from early fire suppression			–0.052
Recent gains in soil carbon from changing agricultural practices			–0.138
Total			–0.350

changes are important in explaining the uptake of carbon observed in U.S. forests during the 1980s.

The estimates of uptake of carbon from direct measurements of forest growth and from changes in land use are both considerably lower than the annual sink of 1.7 ± 0.5 Pg C year⁻¹ inferred from atmospheric data and models (4). That estimate includes Canadian lands south of 51°N, so the sink for the United States alone is presumably less. Some of the difference may also be explained by the time periods included in the analyses. Our estimate and those based on forest inventories were for the 1980s. The analysis based on atmospheric data and models was based on a shorter interval, 1988–1992, that included the eruption of Mt. Pinatubo and anomalously low growth rates of atmospheric CO₂. Thus, the large sink may have been transient. Other estimates of a terrestrial carbon sink in northern mid-latitudes, based on analyses of atmospheric gradients in CO₂, ¹³CO₂, and O₂, vary between 2 and 3.5 Pg C year⁻¹ (28) and suggest a U.S. sink of 0.3 to 0.5 Pg C

year⁻¹ if the sink is assumed to be distributed evenly over northern lands (29).

The accumulations of carbon estimated from forest inventories and land-use change may be low. The analyses do not consider all lands. Forest inventories, in addressing only forests, ignore 70% of the land surface, and natural ecosystems not directly harvested, cleared, or burned were ignored in our analysis. Could such ecosystems be accumulating substantial carbon? It seems unlikely. The total area of these unmanaged lands was only 220×10^6 ha (24% of the land area of the United States) in our analysis, too small to account for much of the difference between 0.2 Pg C year⁻¹ (from land-use change or forest inventories) and ~ 1 Pg C year⁻¹ [from (4)]. The sink would have to average 3.6 Mg C ha⁻¹ year⁻¹ or 85% of the average net

Fig. 3. Annual net flux of carbon in the United States as a result of changes in land use.

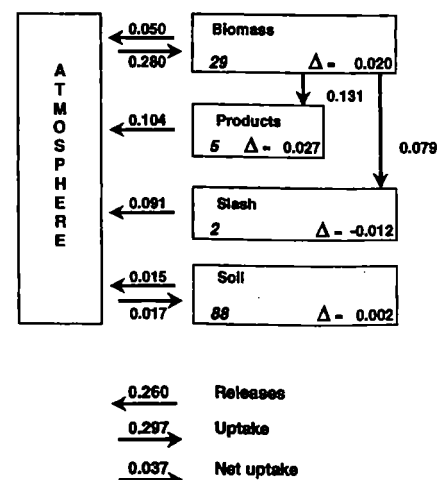
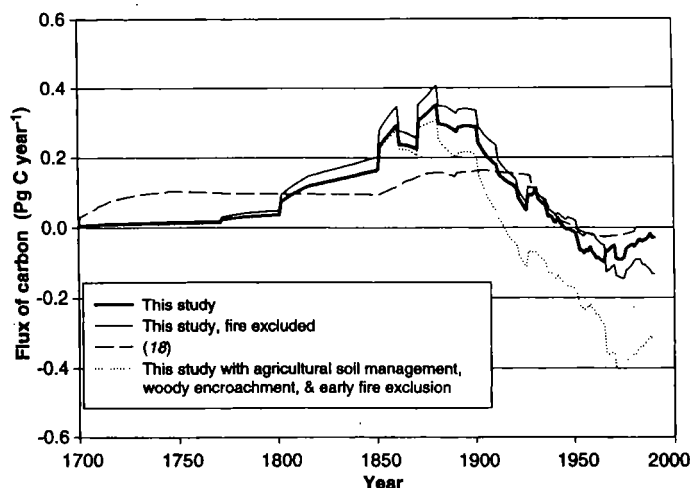


Fig. 4. The amount of carbon in terrestrial carbon pools of the United States in 1990 (petagrams of carbon), changes in these pools (petagrams of carbon per year), and exchanges between these pools and the atmosphere during the 1980s (petagrams of carbon per year).

primary production of terrestrial ecosystems in the contiguous United States (27). Furthermore, forest inventories include the accumulation of carbon in unmanaged as well as managed forests, thus reducing further the area not considered in either analysis.

Perhaps forest soils, which are not measured in forest inventories, are accumulating carbon. We have already noted the large uncertainty in estimates of change in soil carbon (Table 1). In our analysis, we included the accumulation of carbon in soils recovering from abandoned agriculture but not the possible loss (and subsequent recovery) of carbon in forest soils affected by logging. Although some studies have reported such a loss, the data are not consistent (30). Furthermore, a recent analysis of soils in a 55- to 75-year-old New England forest found that soils accounted for only 7 to 15% of the net sink measured for the stand (31). If the estimate is representative, the accumulation of carbon in forest soils is intermediate between those calculated from forest inventories (2, 3) (Table 1).

The evidence is more compelling that carbon is accumulating in agricultural soils as a result of changes in management, but our bookkeeping model did not consider these changes. We calculated that the net loss of soil organic carbon from cultivation and abandonment accounted for about 23% of the long-term net flux attributable to land-use change. Each hectare cultivated lost about 25% of its initial carbon to a depth of 1 m, and during the 1980s, soils were a net sink of $0.002 \text{ Pg C year}^{-1}$ as a result of agricultural abandonment (Fig. 4). However, increased crop productivity since 1960 and, more recently, conservation tillage and the Conservation Reserve Program are likely to have increased further the storage of carbon in agricultural soils. Using the estimates of Donigan *et al.* (32), we calculated an additional rate of accumulation of $0.107 \text{ Pg C year}^{-1}$ for the 1980s. Adding conservation tillage (33) and the Conservation Reserve Program (34) increased the estimated sink in managed soils to $0.138 \text{ Pg C year}^{-1}$ (Table 2).

We also estimated the amount of carbon that might have accumulated as a result of woody encroachment in nonforest ecosystems (21) and the "thickening" of western pine forests that began with fire suppression initiated before systematic collection of data on wildfires (22). All of these processes together (changes in agricultural soils, woody encroachment, and early fire suppression) give an upper estimate for carbon sequestration of $0.35 \text{ Pg C year}^{-1}$ for the entire United States (Table 2). Two of the largest sinks (woody encroachment and early fire suppression) are also the most uncertain, whereas the sinks best documented (from changes in agricultural areas and wood harvests) are small. It is quite possible that the total terrestrial sink during the 1980s averaged only $0.15 \text{ Pg C year}^{-1}$, and thus it is difficult for us to

imagine that an additional sink three to ten times larger (4) has been overlooked. A possible increase in the carbon buried in sediments as a result of human-induced erosion (35) might increase the terrestrial carbon sink further, but the magnitude of carbon burial through erosion is unknown. In contrast to these terrestrial carbon sinks attributable to management of the landscape, the annual release from fossil fuels in the United States averaged $1.230 \text{ Pg C year}^{-1}$ during the 1980s and was 1.447 Pg C in 1996 (36). Management of terrestrial ecosystems appears to have offset only 10 to 30% of the carbon released from fossil fuels.

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16. Harvested wood products decayed at rates of 1 year^{-1} , 0.1 year^{-1} , and 0.01 year^{-1} , corresponding to burned material (including fuel wood), paper, and lumber, respectively.
17. Slash generated during harvests decayed exponentially at rates that varied between 0.02 and 0.06 year^{-1} . Regrowth ranged between 0.3 and $3.0 \text{ Mg C ha}^{-1} \text{ year}^{-1}$ depending on the type of forest and its age [G. L. Ahtay, P. Ketner, P. Duvigneaud, in *The Global Carbon Cycle*, B. Bolin, E. T. Degens, S. Kempe, P. Ketner, Eds. (Wiley, New York, 1979), pp. 129–182; D. E. Reichle, Ed., *Dynamic Properties of Forest Ecosystems* (Cambridge Univ. Press, New York, 1981); J. S. Olson, J. A. Watts, L. J. Allison, *TR004* (U.S. Department of Energy, Washington, DC, 1983)].
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20. The annual flux of carbon calculated by the bookkeeping model is most sensitive to the rates of land-use conversion and to the biomass of ecosystems converted. The errors (and net fluxes) from wood harvest and fires are smaller than those associated with land conversion because the emissions from harvest and fires are offset by the accumulations of carbon in recovering forests. The bookkeeping analysis is least sensitive to rates of decay and growth. For example, if rates of regrowth are overestimated, the uptake per hectare will be too high, but fewer hectares will be regrowing (forests disturbed earlier will have regrown and will no longer be accumulating carbon). If rates of growth are underestimated, rates of accumulation per hectare will be too low, but more hectares will be recovering. On the other hand, if rates of regrowth per hectare have systematically increased over the 290-year period of analysis, as they might have through CO_2 fertilization, the errors in the estimated flux will be larger, especially toward the early years, because most data on rates of growth have been obtained in recent decades of research [see (26)].
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The Not-So-Big U.S. Carbon Sink

Christopher B. Field and Inez Y. Fung

Less than half of the carbon emitted to the atmosphere through deforestation, fossil fuel combustion, and cement manufacture remains in the atmosphere. The remainder of the carbon emitted through these human activities is stored, at least temporarily, in carbon sinks in the oceans and in terrestrial ecosystems.

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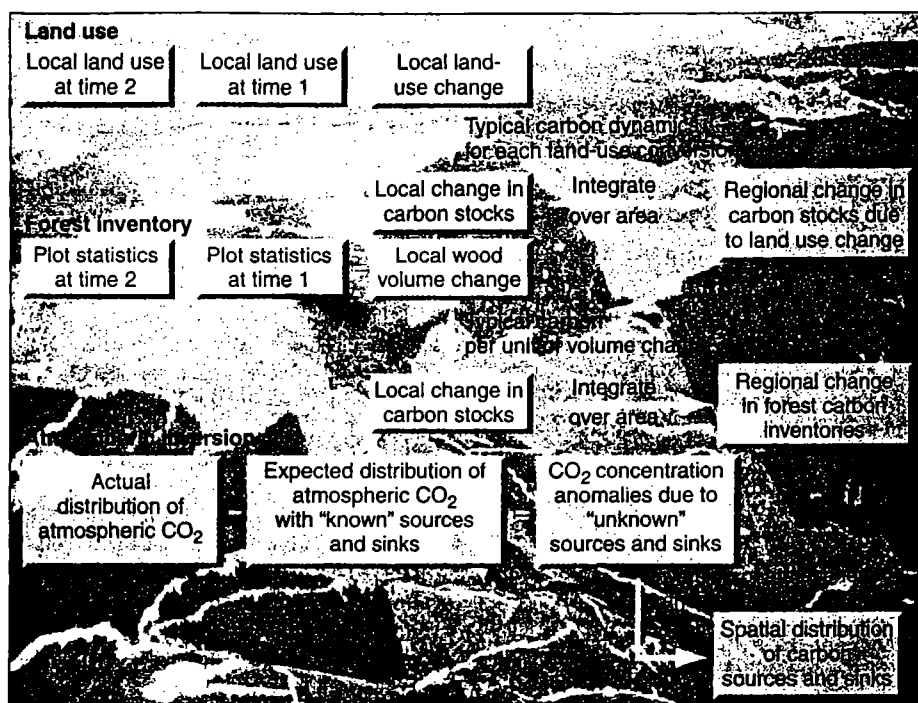
Quantifying these sinks and understanding the underlying mechanisms are top priorities for understanding Earth's major biogeochemical cycles and for establishing how changes in their magnitude could affect the future trajectory of atmospheric CO₂ concentrations.

Measured atmospheric CO₂, ¹³C, and O₂/N₂ distributions indicate that during the past two decades, a substantial fraction of the carbon sink has been on land, in the temperate and boreal latitudes of the Northern Hemisphere (1). However, the mechanisms and the detailed spatial pattern of this

Northern Hemisphere terrestrial sink remain elusive. On page 574 of this issue, Houghton *et al.* (2) synthesize the information on a leading candidate—historical changes in land use—for the United States. They conclude that during the 1980s, U.S. ecosystems accumulated carbon at a rate of 0.15 to 0.35 Pg/year [petagrams (10¹⁵ grams) per year], equivalent to about 10 to 30% of U.S. fossil fuel emissions. This conclusion is consistent with atmospheric analyses (1), which indicate that there is a sink for carbon of about 2 Pg/year north of approximately 30°N (3), although these analyses were unable to constrain the longitudinal distribution of the sink. However, it contrasts sharply with the result of Fan *et al.* (4), who suggest on the basis of atmospheric and oceanic data and modeling that the Northern Hemisphere carbon sink is predominantly North American, south of 51°N, with a magnitude about that of U.S. fossil fuel emissions. The apparent contrast between the conclusions of these two studies highlights the differences between and uncertainties associated with atmospheric “top-down” and terrestrial ecosystem “bottom-up” approaches.

From the perspective of terrestrial processes, the list of candidate mechanisms for

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Quantifying carbon sinks. Schematic diagram of three approaches to quantifying terrestrial carbon sinks that result, at least in part, from changes in land use and land cover.

explaining the terrestrial sink is becoming longer but better quantified. Strictly biogeochemical mechanisms, such as increased plant growth in response to rising temperatures, atmospheric CO₂ concentrations, and nitrogen deposition, are clearly not the exclusive drivers. Elevated CO₂ concentrations and nitrogen deposition stimulate plant growth in many ecosystems (5). Measured responses to elevated CO₂ are generally not large enough, however, to explain the recent terrestrial sink, especially if this sink is concentrated in a small fraction of the land area (6). Recent experimental evidence indicates that elevated nitrogen deposition is also not likely to be a major contributor to the Northern Hemisphere carbon sink (7). Changes in ecosystems in response to past alterations in land management—including changes in timber harvesting, abandonment of agricultural land, and wildfire suppression—are emerging as additional explanations for the terrestrial U.S. carbon sink.

Changes in land management in the Northern Hemisphere are pervasive, with the impact of past changes often persisting for many decades. Until about 1960, cumulative carbon emissions from land-use modification were greater than those from fossil fuel combustion (8). Houghton *et al.* (2) have synthesized historical data on land use with a carbon cycle model (see the figure). According to their analysis, a substantial fraction of the current carbon sink in the Northern Hemisphere appears to be a result of past land management.

The spatial resolution of these conclu-

sions and the attribution of the sink to distinct processes are necessarily coarse. Other independent data on terrestrial sinks can come from national forest inventories. Especially in economically developed regions, these inventories contain many thousands of samplings of nationwide forest resources, collected over several decades. These data, initially collected to quantify harvestable timber, can be analyzed to yield information about changes in forest carbon stocks (see the figure) (9). Data from experimental plots, especially long-term experimental plots in a range of managed and unmanaged ecosystems, are indispensable for improving carbon estimates from both land use and inventory approaches.

Atmospheric data such as the concentrations of CO₂ and O₂ are becoming increasingly useful for inferring terrestrial processes. Large-scale atmospheric measurements generally cannot distinguish between terrestrial mechanisms but rather allow estimates of the overall fluxes of the atmospheric compounds with limited spatial resolution (see the figure). The global network of monitoring stations provides reasonable resolution for interpretation of large latitudinal zones. Quantifying continental sources and sinks is much more technically challenging, a consequence of the small longitudinal gradients, the sparse monitoring network, and the limited capabilities of current atmospheric models. Fan *et al.*'s error analysis (4) clearly reveals this limit. Their central estimate assigns about 75% of the Northern Hemisphere sink to North

America, but one standard deviation around this mean includes both 100% of the sink in North America and a 50-50 balance between North America and Eurasia. An increase in the number and accuracy of the stations that monitor the three-dimensional distribution of atmospheric CO₂, including vertical profiles and column totals, will be critical for assessments seeking greater spatial resolution. Accurate measurements of other atmospheric constituents, including ¹³C, ¹⁴C, O₂, and CO, will be increasingly important for interpreting measurements of CO₂ concentrations and validating hypotheses about carbon sinks.

The growing appreciation of the role of past changes in land management for terrestrial sources and sinks of carbon should stimulate a rethinking of the terrestrial carbon cycle. A substantial carbon source from forest clearing and a subsequent sink from land management have broad implications. Future research on the terrestrial sink may need to focus as sharply on the history of past management as on ecosystem responses to future changes in climate and atmospheric composition. In experimental studies on the carbon cycle, the interaction of global changes with land management should receive the same priority as the responses of natural ecosystems.

Sinks associated with recovery from past land management eventually saturate. The time until saturation is determined largely by the date at which forests started growing. In the United States, a substantial component of the current sink appears to result from long-term consequences of processes begun in the early decades of this century, which may be well on their way to saturation. This also means they are explicitly eliminated from consideration in the Kyoto Protocol as sinks for carbon offsets, because the protocol counts only deliberate actions to reforest, establish new forest, or slow deforestation since 1990.

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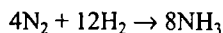
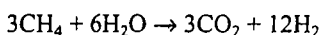


Carbon Sequestration in Soils

William H. Schlesinger

Maintaining and increasing soil organic matter (SOM) adds to soil fertility, water retention, and crop production. Recently, many soil scientists have suggested that the sequestration of atmospheric carbon dioxide in SOM could also contribute significantly to attempts to adhere to the Kyoto Protocol. Conversion of large areas of cropland to conservation tillage, including no-till practices, during the next 30 years could sequester all the CO₂ emitted from agricultural activities and up to 1% of today's fossil fuel emissions in the United States (1). Similarly, alternative management of agricultural soils in Europe could potentially provide a sink for about 0.8% of the world's current CO₂ release from fossil fuel combustion (2). Beyond conservation tillage, however, many of the techniques recommended to increase carbon sequestration in soils contain hidden carbon "costs" in terms of greater emissions of CO₂ into the atmosphere.

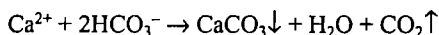
Application of nitrogen fertilizer is often recommended to increase SOM, particularly on lands that have already experienced significant losses in SOM as a result of cultivation (3). At 100% efficiency, the stoichiometry of the Haber-Bosch process for the industrial production of ammonia indicates an emission of 0.375 moles of C per mole of N produced:



Ismail *et al.* (4) found a sequestration of 1250 grams of carbon per square meter (gC/m²) in soils under conventional tillage, and 1740 gC/m² under no-till practices in Kentucky, during 20 years of continuous cultivation of corn receiving nitrogen fertilizer at an annual rate of 336 kg/ha. However, the CO₂ released during the production of the fertilizer was equivalent to 334 gC/m², or 19 to 27% of the carbon sequestration (5). Additional carbon emissions are incurred in the manufacture, transport, and application of fertilizer. A factor of 1.436 moles of CO₂-C released per mole of N more accurately reflects the full carbon cost of N fertilizer (6). This

factor would effectively negate any net carbon sink as a result of the application of the fertilizer.

Increasing the production of plants on marginal, semiarid lands is another method frequently proffered to increase the storage of carbon in soils. In most cases, increasing plant production on these lands will require irrigation, yet irrigation is potentially associated with large CO₂ emissions. The fossil fuel-derived energy used in pumping irrigation water amounts to 22 to 83 gC/m² per year for irrigated lands in the United States (7). This emission is likely to exceed any net carbon sequestration on irrigated agricultural lands. Moreover, groundwaters of arid regions often contain as much as 1% dissolved Ca and CO₂ versus 0.036% in the atmosphere (8). When such waters are applied to arid lands, CO₃ is released to the atmosphere and CaCO₃ precipitates:



For example, taking the water-use efficiency of arid-land plants as 1428 g of H₂O lost per gram of biomass produced (9) and assuming a 50% C content in plant tissue, 0.042 gC is released as CO₂ per gram of C fixed in plant biomass. Thus, if irrigation water containing dissolved Ca at 50 mg/liter is used to increase plant production by 200 gC/m² per year on semiarid land, the net CO₂ released from the formation of soil carbonate would be 8.4 gC/m² per year. If only 1% of added plant production contributes to long-term carbon sequestration in the soil (10), irrigation actually transfers CO₂ from soils to the atmosphere.

Plants grown under high CO₂ concentrations use water more efficiently. Many workers have thus suggested that plant production and soil carbon storage may increase as the concentration of CO₂ rises in Earth's atmosphere. Wood *et al.* (11), using free-air CO₂ enrichment (FACE) technology on arid agricultural lands in Arizona, reported small increases in soil organic carbon as a result of the growth of cotton under high CO₂ concentrations. On their wet plot treatments, application of ~1.0 m of irrigation water (12), likely containing Ca concentrations as high as 50 mg/liter, would annually release 15 gC/m² to the atmosphere from the formation of pedogenic carbonate.

Applications of manure are often assumed to increase carbon sequestration in soils (2), but manure is not likely to yield a net sink for carbon in SOM. Buyanovsky and Wagner (13) showed that SOM increased with increasing C input from residues and manure in the Sanborn plots in Missouri. Manure was applied at an annual rate of 1340 g/m² to fields of corn and wheat. The highest levels of production were for corn, up to 1100 g/m² per year. If all of this crop were used for silage, and assuming the digestion efficiency of livestock is 60% (14), then the production of manure would be 440 g/m². Thus, the entire above-ground plant production on 3.0 ha of land was required to supply the manure to each hectare of manured land. Greater concentrations of SOM in manured fields can thus be expected to be associated with declining SOM on a proportionally larger area of off-site lands. Manuring has a number of practical applications, but net carbon sequestration is not one of them.

A substantial sink for carbon in soils may derive from the application of conservation tillage and the regrowth of native vegetation on abandoned agricultural land. Applications of fertilizer, irrigation, and manuring are important agricultural practices, but we should not be overzealous in estimating their contributions to the Kyoto Protocol. Treaty negotiators must keep in mind the complexities of a full accounting of the carbon emissions and sinks associated with various human activities.

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*original letter
sent to G+ WH*

American Council for an Energy-Efficient Economy • Center for
International Environmental Law • Environmental Defense Fund •
Greenpeace • National Environmental Trust • National Wildlife
Federation • Natural Resources Defense Council • Ozone Action
• Seattle Audubon Society • Sierra Club • U.S. PIRG • Union of
Concerned Scientists • Woods Hole Research Center • World
Wildlife Fund

May 25, 1999

Todd D. Stern
Assistant to the President
for Special Projects
Special Projects Office
The White House
Room G/WW
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Washington, D.C. 20500

Frank E. Loy
Under Secretary
Global Affairs
Department of State
Room 7250
2201 C Street, NW
Washington, D.C. 20520

Dear Messrs. Stern and Loy:

Within the past several months the Administration has made known some of its views on land use, land use change, and forestry (LUCF) under the Kyoto Protocol. We are writing, first, to request that the Administration clarify its position with regard to certain critical issues, and second, if our present understanding of the Administration's position is correct, to express our concerns about that position.

It is clear from the U.S. submissions to the climate secretariat, as well as presentations and statements in recent briefings and workshops, that the Administration favors a "comprehensive" approach to LUCF under the Protocol. It appears that the Administration seeks to enable Parties to take credit for much, if not all, of the

sequestration attributable to biotic sinks that can be scientifically verified, regardless of whether this sequestration exceeds levels projected under "business-as-usual."

Presumably, the United States would seek credit for this sequestration during the first commitment period, by considering forest, agriculture and range management to be additional activities under Article 3.4 of the Protocol.

If this correctly characterizes the Administration's views on Article 3.4, we are deeply troubled. According to the most recent available U.S. government study, such an approach could give the United States 192 million tons of carbon equivalent credit each year during the first commitment period for "business-as-usual" activities, not including agricultural soils and rangeland.¹ This is equivalent to a 13% increase in the U.S. assigned amount during the first commitment period, or approximately a 40% reduction of the level of effort relative to reference case projections that would be required for the United States to meet its Kyoto target. Put another way, it is tantamount to converting the U.S. target from a 7% reduction to a 5% *increase* from 1990 levels. Such a result would be a substantially weaker commitment than President Clinton originally proposed prior to the Kyoto Conference.

In Kyoto parlance, the U.S. approach, as we understand it, amounts to a full "gross/net" accounting of sinks. The compromise adopted in Kyoto, however, was a *limited* gross/net approach. As evidence that the Administration understood and accepted the Kyoto bargain, we note that it announced immediately afterward that the sinks language in the Protocol would account for 3% of the U.S. target—not the 13% change that could result from a full gross/net approach.

In deciding which new activities should be adopted under Article 3.4, care must be taken to preserve the level of effort agreed for the first commitment period by each of the Annex I Parties. Allowing Parties to receive substantial additional credit for "business-as-usual" activities would undermine the Protocol and put the climate at greater risk.

If we have misstated the U.S. position on LUCF, or the impact it would have on the level of effort required of the United States during the first commitment period, we request clarification. If, on the other hand, our characterization of the U.S. position and its implications for the first commitment period is correct, we request that the position be revised to take account of our concerns.

Respectfully,

¹ Joyce, L.A. (ed.), *Productivity of America's Forests and Climate Change*, USDA Forest Service, General Technical Report RM-271. September 1995.

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American Council for an Energy-
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Center for International Environmental
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Union of Concerned Scientists

Kilaparti Ramakrishna
Woods Hole Research Center

Jennifer Morgan
World Wildlife Fund

cc: David Sandalow, CEQ
David Gardiner, EPA
Margo Anderson, USDA
Interagency "Sinks" Group

Send to:

*Mr. Daniel Lashof
Natural Resources Defense Council
1200 NY Ave NW
Suite 400
Wash DC 20005*

*you can
call
Nigel Purvis
to confirm
the addressing.*

OES to answer

US CLIMATE ACTION NETWORK

1367 Connecticut Avenue, NW, Suite 300
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Email: cieline@igc.org

FAX MEMORANDUM
Please Deliver Immediately

To: Frank Loy, 647-0753
Roger Ballentine, 456-6468

CC: Margo Anderson
Ken Andrasko
Peter Backlund
Rosina Bierbaum
Evan Bloom
Bill Breed
David Doniger
Joe Ferrante
David Gardiner
Mark Hambley
Bill Hohenstein
Heather Huppe
Ann Kinzig
Jeff Miotke
Adele Morris
Tom Peterson
David Sandalow

FROM: Nathalie Eddy, USCAN, International Coordinator

DATE: July 13, 1999

PAGES: 6

RE: US negotiating tactics in Bonn

Dear Messrs. Ballentine and Loy,

Attached please find a letter and memo from several US Climate Action Network members.

Sincerely,

Nathalie Eddy

Nathalie Eddy
International Coordinator, USCAN

July 13, 1999

Mr. Frank Loy
Under Secretary
Global Affairs
Department of State, Room 7250
2201 C Street, NW
Washington, DC 20520

Mr. Roger Ballentine
Deputy Assistant to the President for Environmental Initiatives
The White House, Room 107, East Wing
Washington, DC 20502

Dear Messrs. Loy and Ballentine,

A number of US Climate Action Network (USCAN) members would like to bring to your attention some very disconcerting negotiating tactics and policy positions of the U.S. delegation at the most recent session of the subsidiary bodies to the UNFCCC held in Bonn, May 31-June 11, 1999. We found the U.S. behavior to be surprisingly inconsistent with the U.S.' stated support for transparency and sound science in the climate change negotiations.

While the U.S. played a constructive role in Bonn on certain issues, it was dangerously off track on the items of national communications data, land-use, land-use change and forestry (LULUCFs) and international bunker fuels. The U.S. position on all three of these issues demonstrated an alarming lack of commitments to transparency, core principles of information sharing, and consideration of relevant data. This data forms the foundation of the Convention, and ensures the credibility of Parties' inventories and targets. By seemingly discrediting these issues in pursuit of negotiating tactics, the U.S. is contributing to the destabilization of the climate change agenda.

Attached please find a brief report on U.S. behavior in each of these above-mentioned arenas at the Bonn sessions. Please feel free to contact us if you would like more details on any of the issues raised. We look forward to working with you to strengthen the U.S. position. As you prepare for the next round of negotiations in Bonn, October 25-November 5 we would welcome the opportunity to meet with you to discuss these or other issues at greater length.

Sincerely,

Donald Goldberg
Center for International Environmental Law (CIEL)

Jon Sohn
Friends of the Earth (FoE)

Gary Cook

Greenpeace

Michael Noble

Minnesotans for an Energy-Efficient Economy

Boni Biagini

National Environmental Trust (NET)

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James K. Wyerman

20/20 Vision

*UNFCCC Negotiating Sessions, SB10
Bonn, May 31-June 11, 1999*

Report on U.S. negotiating tactics

National Communications and Inventory Guidelines

The unfortunate perception created in this contact group is that the U.S. does not support the transparent and full reporting of emissions data. The U.S. seems especially opposed to reporting on the progress it has made in reducing emissions through its policies. This contradicts the U.S.' commitment to provide such a progress report under the UNFCCC (ratified by the U.S. Senate). Such a non-transparent approach opposes the highly prized "freedom of information" that is supposed to be paramount in American society. It is also inconsistent with standards in U.S. environmental policy as evidenced in the U.S. Toxic Release Inventory.

Together, national communications and inventory guidelines provide the basis for evaluating compliance with the Framework Convention on Climate Change and the Kyoto Protocol. These reports also allow one to evaluate the overall effectiveness of the treaties. For example, if Japan did not seem to be on a trajectory that would level off their emissions by 2006, one could question their ability to comply with the Kyoto Protocol.

The previous guidelines were approved in 1996 at COP2, but the IPCC has since provided improved recommendations.

The U.S. took on a fairly puzzling stance in the contact group discussions on inventory guidelines and national communications. Although the U.S. has been making a commendable investment in improving national inventory accuracy and transparency through the IPCC process, the general tenor of U.S. interventions in Bonn was to obfuscate the reported data and make it more difficult to consume. Here are just two examples that cause concern:

- **SHALL vs. SHOULD:** Almost all of these guidelines are couched using the terms "shall" or "should" such as, "Parties shall report the following information." The EU was the only group of countries arguing in favor of using the word "shall." This is a stronger, more binding, word. It is confusing why the U.S. did not support the EU on this issue. One would think that the U.S. would want it to be a requirement for all data that is to be reported to be required. This would allow the U.S. to evaluate the progress of others, and to determine whether another country has sufficient emissions credits to sell under an international emissions trading regime. Without solid data, it would be virtually impossible to engage in trading without substantial risk, and therefore, more costly. Reporting should not be optional. Does this mean the U.S. does not intend to be fully transparent and report all the data that it should to the world community and its own citizens?

By failing to support the use of the word "shall" the U.S. is weakening the existing mandatory guidelines. In addition, the Kyoto Protocol *mandates* such reporting when it states under Article 7, that "Each Party shall incorporate in its national communication the supplementary information necessary to demonstrate compliance with its commitments." The Framework Convention (Art. 12.2) is equally clear: "Each developed country Party and each other Party included in Annex I shall incorporate in its communication the following elements of information (emphasis added)."

- **INDICATORS:** The U.S. generally argued for eliminating the use of indicators, a standard practice in data presentation. For example, in a paragraph about measuring the results of

greenhouse gas mitigation, the U.S. made the following proposal (deletions stricken out, additions in bold):

Greenhouse gas mitigation monitoring and results. This should cover a description of the way in which progress with policies and measures to mitigate greenhouse gas emissions is monitored and evaluated over time. Institutional arrangements for monitoring of greenhouse gas mitigation policy may also be reported in this context. ~~Parties may also provide information about indicators which assist in the process of monitoring and evaluation. Such indicators may relate to aggregate statistics or detailed sectoral analysis.~~ (U.S.A) Parties may provide the results of monitoring activities, including values of indicators, if used, over time. (U.S.A)

A later draft of the negotiating text completely removed ANY reference to the use of indicators.

The use of indicators is a standard practice. An indicator is simply a combination of raw data, such as per capita emissions (emissions/population). It makes the data more useful and it also allows for easier comparison. Therefore, removing the use of indicators (or not requiring it) will make the reported data more difficult to understand. The U.S. delegate argued that indicators make the data more uncertain, but this is not a compelling argument. A great body of literature has been developed around the use of indicators. They are used all the time, as seen in the UNDP Human Development Index, the WRI Environmental Quality Index, or the World Bank Wealth of Nations Index.

These are but two examples that illustrate our concerns with the U.S. position at the recent Bonn session on national communications data and the review of inventory guidelines. The U.S. performance raised several concerns: Is the U.S. trying to hide the effects of policies on their emissions? Why is the U.S. trying to reduce the usefulness of the data and make it more difficult for average citizens to understand? Why would the U.S. be interested in making reporting requirements optional?

LAND-USE, LAND-USE CHANGE AND FORESTRY (LULUCF)

SBSTA10 was tasked with addressing the policy and procedural elements of taking a decision on the land-use change and forestry articles of the Kyoto Protocol. During the two weeks of SBSTA10, the "sinks contact group" met daily, working through the various elements of the draft conclusions for the session. The most contentious issue discussed was the role of country-specific data and information in the decision-making framework for Articles 3.3 and 3.4 of the Kyoto Protocol. In other words, should countries be requested to provide estimates of the carbon sequestration potential in their countries from various activities e.g. cropland, rangeland and forestry management? The role of data in this context is multi-fold.

Most countries now recognize that the land-use change and forestry decisions that were made in Kyoto were not well-informed due to a lack of data. Even if data had been provided, discussions on these items came much too late in the process to weigh the various factors adequately. For that reason, the Protocol now includes rather incomplete and problematic articles regarding LUCF. Countries attempted in their own calculations to figure the impact of the inclusion of afforestation, reforestation and deforestation on their Kyoto targets. This led to statements by the U.S. that the sinks language in the Protocol would account for 3% of the U.S. target.

It would be more effective to have these types of calculations occur in a more transparent and timely fashion. It is for this reason that the European Union and others at SBSTA10 requested

that country-specific data be part of the decision-making framework, i.e. one of the criteria that is taken into account when deciding which new and additional activities to add to Article 3.4 of the Protocol. The U.S. rejected this call for data throughout most of the SBSTA10 sessions. The U.S. did, however, in the sinks contact group, support language in the draft conclusions on the importance of such data. Those conclusions stated that "Given the importance of country-specific data and information, and of a decision-making framework, the SBSTA decided to begin the consideration, at its eleventh session, of the need for country-specific data and information and its relationship to a decision-making framework in the context of the requirements of the Kyoto Protocol." (FCCC/SBSTA/1999/L.9/(f)) Upon this understanding, members of the Climate Action Network noted that the U.S. had recognized the need for transparency and full provision of information, and we therefore applauded the U.S. for doing so.

This, however, was not the case. During the last session of the SBSTA, the U.S., along with others, moved to delete the first crucial clause of the sentence noting the importance of country-specific data. Such a position opposes to the principles of transparency that the U.S. has supported throughout these negotiations. It appears that the U.S. does not wish to provide data at this time on this highly complex and controversial article of the Protocol. This information is readily available, and one estimate was actually presented in Bonn by an independent scientist from Colorado State University. Preventing the inclusion of this information in the decision-making process is harmful to the international process in general and undermines the foundation of the Convention process. Full data disclosure should be a principle of operation of the United States in these negotiations, thus setting an example for others across the globe.

Bunker Fuels

Throughout the SBSTA10 meeting, the U.S. delegation tried to undermine the text proposed by the SBSTA Chairman on the issue of international bunker fuels. In particular, the U.S. called into question the implications of Decision 2/CP.3, and singled itself out as the only Party to deny that this decision calls for a discussion of the allocation of emissions of international bunker fuels.

Decision 2/CP.3 on Methodological Issues states in para. 4 that "emissions based upon fuel sold to ships or aircraft engaged in international transport should not be included in national totals, but reported separately; and urges the SBSTA to further elaborate on the inclusion of these emissions in the overall greenhouse gas inventories of Parties."

Furthermore, although the Kyoto Protocol requires ICAO (and IMO) to "pursue limitation or reduction of emissions from bunker fuels," a concrete proposal has yet to be placed on the table from these organizations. The U.S. suggestion of leaving the entire responsibility to ICAO and IMO would render a medium term decision highly unlikely. Such a delay in the further negotiation of a proposal is unacceptable.

Prior to SBSTA10, it seemed that the U.S. agreed on the importance of closing the international bunker fuel loophole in time for the negotiation of the second commitment period targets. This, however, is clearly not the case as the U.S. delegation did not see the need for Parties to submit their views on the IPCC Special Report on Aviation, nor the necessity for a formal review of the IPCC Special Report and its implications by the SBSTA or a future COP. Fortunately, the U.S. proposal to generally disregard the IPCC Special Report on Aviation was viewed unfavorably by the majority of Parties, and the final SBSTA10 decision calls for submissions to the secretariat by August 16. SBSTA11 and COP5 offer an opportunity for the U.S. to join other Parties in working toward closing the international bunker fuel loophole and to elaborate an approach to bunker fuel allocation into Parties' targets for the second commitment period.

not in ICAO

DEPARTMENT OF STATE
OFFICE OF THE UNDER SECRETARY FOR GLOBAL AFFAIRS
2201 C Street, N.W., Room 7250
Washington, D.C. 20520

F A X C O V E R S H E E T

DATE: July 9, 1999

TIME: 5:46 PM

TO: Climate Group

FAX: As indicated

FROM: Nigel Purvis
Senior Adviser

PHONE: (202) 647-8745
FAX: (202) 647-0753

RE: SINKS MEETING ON MONDAY AT 4:00, ROOM 7250

Number of pages (including cover sheet):

Attached is a draft paper for the Monday meeting.

Climate Change List of Participants
Policy Development
Mondays, 4pm

<u>Name</u>	<u>Organization</u>	<u>Phone</u>	<u>Fax</u>
Aldy, Joe	WH/CEA	395-1455	395-6958 ✓
Ballentin, Roger	WH/LEG	456-6493	456-6468 ✓
Boorstin, Robert	Treasury	622-0486	622-0073 ✓
Bowles, Ian	WH	395-5750	456-2710 ✓
Cumby, Robert	Treasury	622-0572	622-2633 ✓
Doniger, David	EPA	260-7400	260-5155 ✓
Frampton, George	WH/CEQ	456-6224	456-2710 ✓
Gardiner, David	WH	260-4332	260-0275 ✓
Gibson, John	WH/CCTF	395-2321	395-2342 ✓
Goldwyn, David	Energy	586-8660	586-7169 ✓
Hales, David	USAID	712-1451	216-3174 ✓
Hendricks, Bracken	Commerce	482-3604	501-8066 ✓
Holstein, Elgie	OMB	395-4561	395-4639 ✓
Lawrence, Robert	WH/CEA	395-5046	395-6958 ✓
Mazur, Mark	DOE	586-5316	586-3047 ✓
Orfini, Michael	WH/OVP	456-9515	456-9500 ✓
Perjesepie, Bob	EPA	260-7400	260-5155 ✓
Reicher, Dan	Energy	586-9220	586-9260 ✓
White, Bill	EPA	260-3711	260-4852 ✓

GADMIN: Climate Change List of Participants

Sinks
(Draft: 7-9-99)

Issue for Decision

Environmental NGOs have questioned our approach to Article 3.4 of the Kyoto Protocol, fearing that we seek to change a 7 percent reduction commitment into a 5 percent increase by claiming credit for "business-as-usual" sequestration activities -- an Administration response is needed.

Article 3.4

- This provision allows for expanding the list of human-induced sink activities that may be used to offset emission limitation commitments (e.g., to sequestration in agricultural soils, land use changes, forest conservation practices), if Parties can agree on them by consensus.
- Any such decision would apply in the second commitment period and later (i.e., after 2012); but a Party could also choose to apply the decision to offset its commitment in the first budget period, if the activities claimed had taken place since 1990.

Near Term versus Long Term

- Environmental NGOs largely see the Article 3.4 issue in terms of how it will affect the U.S. target in the first budget period, and they oppose weakening that commitment through the addition of "business-as-usual" sequestration activities.
- There are two issues at work, and it may be useful to separate them: 1) what makes sense in terms of the development of the convention and our efforts to address climate change over the long term; and 2) how would decisions that make sense in that context affect commitments in the first budget period?
- It is important to "get it right" for the long term; separately, we can consider whether and to what extent Parties should be able to benefit from such a decision in the first commitment period.

Article 3.3

- This provision limits the human-induced sink activities that must be used to offset emission targets in the first budget period to afforestation, reforestation and deforestation since 1990.

- The Protocol does not provide for Parties to elaborate these terms, although the IPCC is examining various approaches now in use in its Special Report due later this year.

Near Term versus Medium Term

- Environmental groups have also raised concerns that a particular approach to Article 3.3 would allow Parties to claim credit for replanting trees without penalizing the harvesting of trees (an asymmetry)
- The asymmetry of Article 3.3 would benefit the United States, but we don't know to what precise extent.
- The negotiating history supports this asymmetry (Canada insisted in Kyoto that "harvesting" be deleted, and "reforestation" would allow Parties to benefit from replanting), but the IPCC Special Report will criticize it and Parties will likely be uncomfortable arguing for it internationally.
- Still, before rejecting Article 3.3's asymmetry, two things will be important:
 - 1) are there trade offs to be made internal to the Article 3.3/3.4 debate (e.g., drop the asymmetry in exchange for support on the inclusion of certain Article 3.4 activities)?
 - 2) are there trade offs between Article 3.3 and other issues (e.g., "supplementarity")

Timing Questions

- To preserve negotiating flexibility, it will be important that decisions on Article 3.3 and Article 3.4 are taken at the same time.
- The risk and greater likelihood is that there will be pressure to take decisions on Article 3.3 first, and to defer decisions on Article 3.4 until some later date.

DRAFT

June 30, 1999

Mr. Daniel Lashof
Natural Resources Defense Council
1200 NY Ave, NW, Suite 400
Washington, DC 20005

Dear Mr. Lashof,

Thank you for your letter of May 25th regarding land use, land use change and forestry (LULUCF).

You are correct that the United States advocates a comprehensive, or full, carbon accounting for sequestration and emissions of greenhouse gases from LULUCF. We have adopted this approach, not to maximize the amount of sequestration for which we might claim credit, but to provide the greatest possible environmental benefit over the long run. Only by ensuring that all emissions and sequestration are counted will we provide the greatest possible incentive for the conservation of our agricultural and forestry resources. We will also avoid some of the perverse incentives that now exist. Limited to just the three activities listed in Article 3.3, for instance, the Protocol would allow Parties to harvest an old-growth forest, replant and be debited for no net emissions. Even though significant levels of greenhouse gases would be released from the cutting of the underbrush and disturbance of the soil, these emissions would not be counted against the Party. A comprehensive approach to new activities under Article 3.4 would avoid this and other similarly unfortunate outcomes.

More generally, a wide variety of agricultural and forestry practices can result in significant emissions of a number of greenhouse gases. I suspect that you may share our belief that emissions from the full range of land use, land use change, forestry, and agricultural activities should not go unaccounted for under the Kyoto Protocol. In

1 addition, promoting sequestration in agriculture and
2 forestry could provide important ancillary benefits while
3 helping to address climate change. Including a broad range
4 of LULUCF activities under the Protocol is therefore
5 crucial.

6
7 I should clarify that, after the Kyoto Protocol was
8 negotiated, the United States did not announce that sinks
9 would only account for three percent of the U.S. target.
10 On the contrary, the Administration was merely noting that
11 just the change from a net/net to a gross/net approach
12 effectively made the U.S. target three percent less
13 stringent. Although we were not able at that time to
14 quantify the additional tons that might be sequestered
15 through new activities, the Parties clearly understood in
16 Kyoto that Article 3.4 could provide additional flexibility
17 above and beyond that provided by Article 3.3 and by the
18 change to a gross/net approach. We had every expectation
19 that new activities would help the United States meet its
20 target and, in the process, provide significant
21 environmental benefits.

22
23 Nonetheless, we are not advocating the unlimited use of new
24 LULUCF activities. We believe that the emissions and
25 sequestration from all new activities must be measurable
26 and verifiable. Those sequestration and emissions must
27 also be human-induced and have taken place since 1990. We
28 would welcome your thoughts on how Parties might
29 demonstrate that emissions and sequestration from proposed
30 activities are human-induced, measurable, and verifiable.
31 We would also appreciate your suggestions on the
32 appropriate process under the Protocol for deciding whether
33 proposed activities meet these criteria.

34
35 Thank you again for your interest. We look forward to
36 receiving further input from you on this and other climate
37 change issues.

38
39 Sincerely,
40
41
42

American Council for an Energy-Efficient Economy • Center for
International Environmental Law • Environmental Defense Fund •
Greenpeace • National Environmental Trust • National Wildlife
Federation • Natural Resources Defense Council • Ozone Action
• Seattle Audubon Society • Sierra Club • U.S. PIRG • Union of
Concerned Scientists • Woods Hole Research Center • World
Wildlife Fund

May 25, 1999

Todd D. Stern
Assistant to the President
for Special Projects
Special Projects Office
The White House
Room G/WW
1600 Pennsylvania Avenue, NW
Washington, D.C. 20500

Frank E. Loy
Under Secretary
Global Affairs
Department of State
Room 7250
2201 C Street, NW
Washington, D.C. 20520

Dear Messrs. Stern and Loy:

Within the past several months the Administration has made known some of its views on land use, land use change, and forestry (LUCF) under the Kyoto Protocol. We are writing, first, to request that the Administration clarify its position with regard to certain critical issues, and second, if our present understanding of the Administration's position is correct, to express our concerns about that position.

It is clear from the U.S. submissions to the climate secretariat, as well as presentations and statements in recent briefings and workshops, that the Administration favors a "comprehensive" approach to LUCF under the Protocol. It appears that the Administration seeks to enable Parties to take credit for much, if not all, of the

sequestration attributable to biotic sinks that can be scientifically verified, regardless of whether this sequestration exceeds levels projected under "business-as-usual."

Presumably, the United States would seek credit for this sequestration during the first commitment period, by considering forest, agriculture and range management to be additional activities under Article 3.4 of the Protocol.

If this correctly characterizes the Administration's views on Article 3.4, we are deeply troubled. According to the most recent available U.S. government study, such an approach could give the United States 192 million tons of carbon equivalent credit each year during the first commitment period for "business-as-usual" activities, not including agricultural soils and rangeland.¹ This is equivalent to a 13% increase in the U.S. assigned amount during the first commitment period, or approximately a 40% reduction of the level of effort relative to reference case projections that would be required for the United States to meet its Kyoto target. Put another way, it is tantamount to converting the U.S. target from a 7% reduction to a 5% *increase* from 1990 levels. Such a result would be a substantially weaker commitment than President Clinton originally proposed prior to the Kyoto Conference.

In Kyoto parlance, the U.S. approach, as we understand it, amounts to a full "gross/net" accounting of sinks. The compromise adopted in Kyoto, however, was a *limited* gross/net approach. As evidence that the Administration understood and accepted the Kyoto bargain, we note that it announced immediately afterward that the sinks language in the Protocol would account for 3% of the U.S. target—not the 13% change that could result from a full gross/net approach.

In deciding which new activities should be adopted under Article 3.4, care must be taken to preserve the level of effort agreed for the first commitment period by each of the Annex I Parties. Allowing Parties to receive substantial additional credit for "business-as-usual" activities would undermine the Protocol and put the climate at greater risk.

If we have misstated the U.S. position on LUCF, or the impact it would have on the level of effort required of the United States during the first commitment period, we request clarification. If, on the other hand, our characterization of the U.S. position and its implications for the first commitment period is correct, we request that the position be revised to take account of our concerns.

Respectfully,

¹ Joyce, L.A. (ed.), *Productivity of America's Forests and Climate Change*, USDA Forest Service, General Technical Report RM-271. September 1995.

Howard Geller
American Council for an Energy-
Efficient Economy

Donald Goldberg
Center for International Environmental
Law

Annie Petsonk
Environmental Defense Fund

Gary Cook
Greenpeace

James Lyon
National Wildlife Federation

Daniel Lashof
Natural Resources Defense Council

Kert Davies
Ozone Action

Stephanie Matheny
Seattle Audubon Society

Ann Mesnikoff
Sierra Club

Katherine Silverthorne
U.S. PIRG

Emily Smith
National Environmental Trust

Peter Frumhoff and Darren Goetze
Union of Concerned Scientists

Kilaparti Ramakrishna
Woods Hole Research Center

Jennifer Morgan
World Wildlife Fund

cc: David Sandalow, CEQ
David Gardiner, EPA
Margo Anderson, USDA
Interagency "Sinks" Group

Send to:

*Mr. Daniel Lashof
Natural Resources Defense Council
1200 NY Ave NW
Suite 400
Wash DC 20005*

*you can
call
Nigel Purvis
to confirm
the addressing.*

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environment

+

Agriculture

& Global **climate change**

A Review of Impacts to U.S. Agricultural Resources

+

Richard M. Adams

OREGON STATE UNIVERSITY

Brian H. Hurd

STRATUS CONSULTING INC.

John Reilly

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

+



PEW CENTER

Global CLIMATE
CHANGE

FOR IMMEDIATE RELEASE:
February 10, 1999

CONTACT:
Shannon Hunt / Kelly Sullivan
(202) 289-5900

New Study Details Effects of Climate Change On U.S. Agriculture

*Projected Regional Impacts on Agriculture Outlined:
New Report is First in Series Examining Environmental Impacts of Climate Change*

WASHINGTON, DC – Climate change has the potential to affect livestock and crops, local agricultural economies and crop production trends according to a new report by the Pew Center on Global Climate Change, which examines the effects of climate change on agriculture. The report finds that while climate change is not expected to threaten the ability of the U.S. to produce enough food to feed itself through the next century, some U.S. agricultural regions, particularly in the north, are expected to benefit, while others, primarily in the south, could face adverse impacts.

The report, released today at a press conference on Capitol Hill, notes that the resiliency and adaptability of the U.S. agricultural sector has made it one of the country's most productive industries and gives the sector the ability to adapt to the changes associated with climate change. However, the report also finds that there remains a potential for negative effects, and particular regions, especially those in the south, will face greater obstacles in adapting to the challenges posed by climate change.

"Anyone with a stake in agriculture should be interested in the findings of this report, which shows that the farming industry we know today will not be the same in the future under the effects of climate change," said Eileen Claussen, Pew Center Executive Director.

At Wednesday's press conference, Agriculture Committee Chairman Richard Lugar (R-IN) and Senator Bob Kerrey (D-NE) both issued statements supporting the Pew Center's efforts to inform American agricultural producers about the potential impacts of climate change.

According to the report, climate change could cause grain yields to fall significantly in southern states, while in the north, longer growing seasons could increase yields of grains such as wheat. Changes in grain production and foraging regions could also cause shifts in the locations of livestock production. Uncertainty in the models does not allow precision in identifying localized effects.

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The Pew Center On
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brings a new cooperative
approach and critical
scientific, economic and
technological expertise
to the global debate on
climate change.

(con't)

The study finds that in order to develop the most accurate and credible assessment of the possible impacts of climate change, it is important to consider adaptation and human response, as well as to continue to develop improved climate change forecasts. But, given the potential impacts, farmers and the agricultural community must consider new strategies in the face of uncertainty.

The report states that the emerging consensus from modeling studies is that the net effects on U.S. agriculture, with a doubling of carbon dioxide in the atmosphere, may be small. But, these models may understate long-range impacts if the rate or magnitude of greenhouse gas emissions exceed projected levels. For example, extreme events – such as storms, droughts and early and late frosts caused by climate change – also could play a role in determining the ultimate impact of climate change on agriculture.

Additionally, secondary impacts of climate change, such as the potential for higher ozone levels, impacts on water resources and pest populations, contribute to the uncertainty and pose additional challenges not only to individual producers, but also larger agricultural economies.

The value of U.S. agricultural commodities exceeds \$165 billion at the farm level and over \$500 billion after processing and marketing.

“The role of the U.S. agricultural sector is too important for us to ignore these findings,” said Claussen. “The agricultural community can adapt to climate change, but adaptation takes time and resources, and with uncertainties related to the timing and magnitude of temperature changes, not all opportunities for adaptation are likely to be realized.”

This report is the first in a series of environmental impact reports slated to be released by the Pew Center this year. Other reports in this series will assess what is known about the impact of climate change on weather and includes analyses of its impact on water resources, coastal areas, human health, ecosystems, and forests.

A copy of the report, “A Review of Impacts to U.S. Agricultural Resources,” is available on the Pew Center web site at www.pewclimate.org.

The Pew Center was established in May 1998 by the Pew Charitable Trusts, one of the nation's largest philanthropies and an influential voice in efforts to improve the quality of America's environment. The Pew Center is conducting studies, launching public education efforts, promoting climate change solutions globally and working with businesses to develop marketplace solutions to reduce greenhouse gases. The Pew Center is led by Eileen Claussen the former U.S. Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs.



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approach and critical
scientific, economic and
technological expertise
to the global debate on
climate change.



EILEEN CLAUSSEN

Eileen Claussen is the Executive Director of the Pew Center on Climate Change. She is the former Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs. In that capacity, she was responsible for developing and implementing policy on behalf of the United States on major international issues, including climate change; ozone depletion; chemicals; natural resource issues, including forests, biodiversity, oceans, fisheries and wildlife conservation; and the sustainable development efforts of the multilateral development banks and the United Nations.

Prior to joining the Department of State, Ms. Claussen served for three years as a Special Assistant to the President and Senior Director for Global Environmental Affairs at the National Security Council. In this role, she was responsible for policy development on a wide range of global environment and population issues. During this time, she also served as Chairman of the United Nations Multilateral Montreal Protocol Fund.

From 1987 to 1993, Ms. Claussen was Director of Atmospheric Programs at the U.S. Environmental Protection Agency. There, she directed international and domestic activities related to the depletion of the ozone layer; developed the acid rain program under Title IV of the Clean Air Act; negotiated the Clean Air Accord with Canada; and directed the development of EPA's energy efficiency programs, including the Green Lights program and the Energy Star program. Ms. Claussen also served from 1990 to 1991 as the Deputy Assistant Administrator for the Office of Air and Radiation. Between 1972 and 1987, she directed various programs at the U.S. Environmental Protection Agency, including those dealing with the land disposal of hazardous waste.

Ms. Claussen is the recipient of the Department of State's Career Achievement Award, the Meritorious Executive Award for Sustained Superior Accomplishment, the Distinguished Executive Award for Sustained Extraordinary Accomplishment, and the Fitzhugh Green Award for Outstanding Contributions to International Environmental Protection. At the conclusion of her government career, she served as the Timothy Atkeson Scholar in Residence at Yale University. She received a Master of Arts degree from the University of Virginia, and a Bachelor of Arts degree from George Washington University.

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to the global debate on
climate change.



ABOUT THE AUTHORS

“Agriculture and Global Climate Change: A Review of Impacts to U.S. Agricultural Resources”

Richard M. Adams

Oregon State University, Corvallis, OR

Richard M. Adams received his Ph.D. in Agricultural Economics from the University of California, Davis, in 1975. He is currently a professor of Agricultural and Resource Economics at Oregon State University, a position he has held since 1983. His research interests include the economic analysis of resource and environmental issues, with emphasis on the consequences of environmental change. Professor Adams has served on numerous governmental advisory and research committees dealing with environmental issues. He has published over 160 journal articles, book chapters and research reports, including 20 on the effects of climate change on agriculture and agricultural resources. He has served on the editorial boards of five journals and was editor of the American Journal of Agricultural Economics from 1992 to 1994.

Brian H. Hurd

Stratus Consulting Inc., Boulder, CO

Brian H. Hurd is a Senior Associate in the climate change group at Stratus Consulting, a Boulder-based environment and energy research firm. He received his Ph.D. in agricultural economics from the University of California, Davis in 1992, where he analyzed technology changes in production agriculture. His passion for interdisciplinary research and for contributing to public decision-making regarding natural resources has led to his current focus on climate change. He has developed regional and national models of water resource impacts, analyzed land use changes in forestry and agriculture, and investigated adaptation and mitigation strategies, while serving a variety of public- and private-sector clients such as U.S. EPA, U.S. Department of Energy, National Science Foundation, National Institute for Global Environmental Change, and the Electric Power Research Institute.

John Reilly

Massachusetts Institute of Technology, Cambridge, MA

Dr. Reilly is the Associate Director for Research in the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology. He spent 12 years with the Economic Research Service of USDA, most recently as the Acting Director and Deputy Director for Research of the Resource Economics Division. He has been a scientist with Battelle's Pacific Northwest National Laboratory and with the Institute for Energy Analysis, Oak Ridge Associated Universities. He received his Ph.D. in economics from the University of Pennsylvania in 1983 and holds a BS in economics and political science from the University of Wisconsin. He has conducted research on the economics of climate change for 19 years. He was a principal author for the Intergovernmental Panel on Climate Change's Second Assessment Report and has served on many Federal government and international committees on climate change and agricultural research.

Agriculture and Global Climate Change

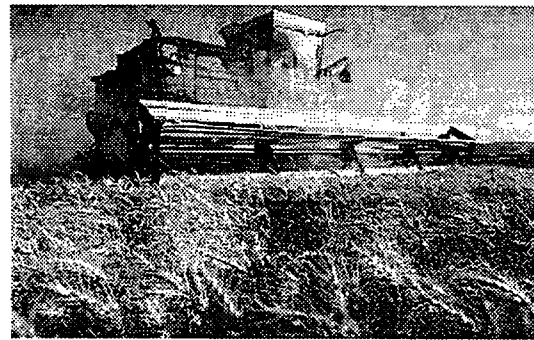
America's agricultural sector depends upon a predictable climate. A recent report by the Pew Center on Global Climate Change examines the current state of knowledge about the effects of climate change on agriculture.

The report finds that while climate change is not expected to threaten the ability of the U.S. to produce enough food to feed itself through the next century, some U.S. agricultural regions, particularly in the north, are expected to benefit, while others, primarily in the south, could face adverse impacts.

The agricultural community can adapt to climate change by developing new crop varieties, increasing irrigation, and changing tillage practices. But adaptation takes time and resources, and with uncertainties related to the timing and magnitude of temperature changes, not all opportunities for adaptation are likely to be realized.

In addition, government policies, prices and technology development will all influence the ability of this sector to adapt.

The emerging consensus from modeling studies is that the net effects on U.S. agriculture with a doubling of carbon dioxide in the atmosphere are likely to be small.



But the projections of these models could understate long-range impacts if the rate or magnitude of greenhouse gas emissions exceed projected levels. Extreme events caused by climate change such as storms, droughts, early and late frosts, could also play a role in determining the ultimate impact of climate change on agriculture, but cannot yet be modeled with confidence.



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MEDIA ALERT.....MEDIA ALERT.....MEDIA ALERT.....MEDIA ALERT

**YOU ARE INVITED TO A NOON PRESS BRIEFING
TO RECEIVE AN ECONOMIC REPORT
ABOUT AN ASSAULT ON AMERICA'S FAMILY FARMS**

Five major U.S. agricultural groups will release and discuss a new economic report that details an assault on America's family farms. Interviews with principals will be available!

The press briefing will be conducted by principals from the National Grange, American Farm Bureau Federation, National Cattlemen's Beef Association, American Corn Growers Association, and United Fresh Fruit & Vegetable Association.

The economic report by Sparks Companies, Inc. details how the Clinton Administration-approved Kyoto Climate Treaty could reduce U.S. farm income by \$21.5 billion, increase consumers' food costs by \$18 billion, reduce U.S. agricultural exports by \$3.6 billion, and cause farmers \$16.2 billion in increased farm production costs.

Kermit W. Richardson, Master (president) of the National Grange, will be present for personal interviews, along with principals from the other farm and commodity groups.

You are invited to the noon press briefing:

WHAT: Economic report on consequences of
the Kyoto Climate Treaty

DATE: Tuesday, February 16, 1999

TIME: 12:00 Noon

WHERE: American Farm Bureau Federation
600 Maryland Avenue, S.W.
Suite 800

CONTACT: Tom Rugg or Tracey Taylor -- 202/628-3507

NATIONAL

Grange News



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For Immediate Release

CONTACT: Tom Rugg
202/628-3507

KYOTO CLIMATE TREATY THREATENS AMERICA'S FAMILY FARMS. ACCORDING TO MAJOR U.S. AGRICULTURAL ORGANIZATIONS

WASHINGTON, D.C. (Feb. 16, 1999) -- Five major U.S. agricultural groups met here today to warn that the Kyoto Climate Treaty is an assault on America's family farms, and could result in higher food costs for U.S. consumers. The treaty has been approved by the Clinton Administration, but must be ratified by the U.S. Senate.

The National Grange joined the American Farm Bureau Federation, National Cattlemen's Beef Association, United Fresh Fruit & Vegetable Association, and American Corn Growers Association at a noon press conference to release an economic study of the treaty's potential impact on American agriculture and family farms. The study was prepared by Sparks Companies, Inc., and co-sponsored by the five food and agricultural organizations.

The global climate treaty is an outgrowth of a meeting in Kyoto, Japan in December, 1997, where 180 world nations met to develop a legally binding international treaty to reduce greenhouse gas emissions. The resulting Kyoto Protocol requires the U.S. and a handful of other developed nations to reduce their emissions to specific levels by 2008-2012. Emerging nations, many of which are major sources of greenhouse gas emissions, exempted themselves from the Protocol.

"The economic costs of the Kyoto Protocol will be enormous to U.S. producers," says National Grange Master (president) Kermit W. Richardson. "We expect higher farm production costs, reduced farm income, and lower demand for agricultural products resulting from the Protocol's forced regulations. It will be especially difficult for U.S. producers to comply with the requirements."

Sparks' 40-page report predicts a possible reduction of \$3.6 billion in U.S. agricultural exports, fewer small family farms due to higher energy costs, and costs of \$16.2 billion in higher farm production costs, \$5 billion in reduced farm sales, \$18 billion in higher consumers' food prices, and \$21.5 billion in reduced farm income.

Presented at the press briefing.

The Kyoto Protocol

An Assault on an American Institution

The family farm is an American institution. More than any other industry, U.S. agriculture defines us as a people and as a Nation. In the past, American farmers have coped with drought and disease, falling prices, and shrinking profits. Now, the family farm faces a new threat – the Kyoto Protocol – that will bring unexpected hardship to many should it be enacted as official U.S. policy.

From the wheat farmers on the Great Plains to fruit and vegetable producers in California, Florida, and across the South, America's farmers produce the bounty that feeds the U.S. and the world.

Not only does agriculture play a key role in feeding the people of the world, it contributes significantly to the U.S. economy. Agriculture and related food distribution account for nearly \$1 trillion in total sales or 13 percent of the total U.S. gross domestic product (GDP). Agriculture in the U.S. is a vital domestic industry, providing jobs to 23 million American workers or 17% of the total labor force. Exports of agricultural products also help to balance our trade with other nations, with nearly \$54 billion in total sales abroad.

Recent technological investments have made the U.S. agriculture industry the most advanced in the world. However, farming remains an energy intensive industry. Diesel, gasoline, electricity, and other forms of energy are required to produce the crops and livestock that feed the world. As a result, the agricultural sector is extremely vulnerable to changes in energy costs.

In addition, U.S. agriculture has invested heavily to insure that it is competitive in foreign markets – the single most important area of growth for U.S. farms. Not only has the industry cut costs to compete, but the federal government has realigned policies to end price supports and other interventions that reduce competitiveness. Consequently, in 1998, agricultural exports could reach nearly \$54 billion and contribute more than \$18 billion to our balance of trade. If the Kyoto Protocol is implemented, U.S. agricultural exports could be reduced by \$3.6 billion – a loss in the range of 6-7% of total exports.

The Kyoto Protocol

In December 1997, over 180 nations met in Kyoto, Japan, to finalize negotiations on a legally binding international treaty aimed at lowering greenhouse gas emissions. The new treaty – called the UN Kyoto Protocol – requires a handful of nations, including the United States, to reduce their greenhouse gas emissions to specific levels by the years 2008-2012. While each country accepted a different level of emission reductions, on average the agreement seeks to reduce total world greenhouse gas emissions to 5% below 1990 levels during this period.

For its part, the United States agreed to reduce its emissions to 7% below 1990 levels by this timeframe. Additional emission reductions will be required in the second budget period (2013-2018), and the level of reductions required in that timeframe will be the subject of future international negotiations.

Key aspects of the Protocol include:

- The agreement covers six gases (CO₂, methane, nitrous oxide, HFCs, PFCs, and SF₆).
- Countries with emerging economies such as China, India, Mexico, and South Korea, exempted themselves from the Protocol.
- The definition of sinks (objects that clean, or remove emissions, from the atmosphere) was limited to include only forestry activities. Agricultural crops and other vegetation are not considered sinks by the Kyoto Protocol.
- Enforcement measures of the Protocol by the United Nations were left undefined and will be the subject of future international negotiations.

Economic Costs of Kyoto

In defending the Kyoto Protocol, the Administration claims this change in national energy policy will not adversely impact the agriculture industry. In contrast, several studies conducted by leading economic forecasting firms and the Energy Information Administration (the federal government's own energy forecasting agency) provide starkly different predictions. Using analysis developed by Standard & Poor's Data Resource International (DRI), this study shows that implementation of the Kyoto Protocol will mean, by 2010:

- **Fewer small, family farms.** Higher energy costs, together with the reduced domestic and export demand could lead to a severe decline in agricultural investment, and a sharp increase in farm consolidations. The number of small farms likely would decline much more rapidly than under business-as-usual conditions.
- **Higher production costs.** Production costs could increase by up to \$16.2 billion (8.8%) and would be difficult for agriculture to pass on to consumers. These higher production costs include a \$13 billion increase in manufactured input (fuel, fertilizer, and chemicals) expenditures, a \$1.6 billion increase in farm origin (feed, livestock, and seed) inputs, and a \$1.9 billion increase in general operating expenses.

- **Lower demand for agricultural products.** Weaker demand for agricultural products results both from the 1.6% decline in GDP and 2.4% decrease in consumers' disposable income. U.S. farmers would be forced to compete with producers in developing countries who do not face emission constraints. These changes could reduce sales by \$5 billion at the farm level.
- **Reduced farm income.** As a result of reduced agricultural revenues and increased production costs, net farm income could be reduced \$21.5 billion from 1998 levels to \$24 billion – more than a 50% decline.
- **Increased marketing costs.** Costs of processing, storing, transporting and handling commodities and food products would increase. The wider marketing spreads could boost consumers' food expenditures nearly \$18 billion.
- **Higher food costs.** The increase in food marketing costs would be small for the average U.S. consumer who spends 11.9% of disposable income on food. However, 37% of U.S. households have less than \$20,000 in after-tax income and spend from 21.2% to more than 100% of their after-tax income on food. In these families, infants and children would experience the greatest impact to their diets.
- **Higher food program costs.** For example, USDA spends more than \$39 billion for six food assistance programs, including the Food Stamp and Child Nutrition Programs. For these programs alone, emission controls from the Protocol could add 500,000 persons to Food Stamp rolls and increase program costs up to 5% annually.

Conclusion

The Kyoto Protocol is a flawed treaty that will have a dramatically negative impact on the U.S. agriculture industry. The family farm, an American institution, will be put at risk for a treaty that exempts other competitor nations from the same types of energy restrictions and higher costs that American farmers will be forced to endure.

For More Information

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