Framework Report on the Development of the National Carbon Monitoring System

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1. Executive Summary

This report chronicles the development of the carbon monitoring system (CMS) for indigenous forests, scrub and soils. Indigenous forests, scrub, and soils represent large terrestrial carbon reservoirs subject to impact from anthropogenic causes such as land-use change that can alter the level of carbon in the soil, change in forest condition such as die back from pest damage, or scrub regeneration from abandoned farmland. Monitoring these changes is important to meet international obligations and to understand the critical mitigation options for reducing our greenhouse gas emissions.

At present it is uncertain whether New Zealand is losing or gaining carbon from these reservoirs, but their good management could assist in phasing the reduction of greenhouse gas production in industry and transport by providing an interim net offset.

As 1990 has been set as the reference year from which carbon changes should be measured, calculating a baseline from that date is an essential aspect of the system. A system that monitors carbon as a requirement also monitors other aspects of soil and forest health. Hence from the outset the development of the CMS considered some of the broader monitoring requirements involved in managing soils and indigenous forests.

However, before possible extensions of the CMS were considered, the basic requirements in relation to carbon measurements had to be met. This meant that the CMS had to:

- provide unbiased (accurate) carbon estimates
- provide estimates within reasonable bounds of error and estimate those bounds (confidence intervals)
- monitor the unexpected and unpredictable
- be capable of measurement over the long term (40–50 years)
- be robust to change over the long term
- provide a basis and data for future, unknown requirements
- be capable of partitioning results into subdivisions whose definitions are currently unknown
- be consistent with other developed countries
- withstand international scrutiny.

The soils, scrub and indigenous forests monitoring systems followed different development routes that reflected the historical information researchers brought to their development, the current level of available technology to supplement on the ground measurements, and the ancillary requirements for other monitoring systems. Where possible, the two systems sought to work together to maximise efficiency but, in general, their development occurred in parallel. A third component of the CMS development was the consideration of an information system to manage and report on the data. While considerable thought has been given to the system, the user requirements are not currently sufficiently well defined to

finalise the system. This definition is not scheduled to occur until the second year of implementation.

A key requirement of the CMS will be a regularly updated Land Cover Database. The intention is that this will be provided from remotely sensed imagery, supplemented with other information. On-going research should also be available to make improvements to monitoring methodologies and to provide an independent audit on the carbon estimates.

During the CMS development an international review of the system was held in time for the key recommendations of the review to be undertaken before the development phase was concluded.

2. Climate Change and Greenhouse Gas Mitigation

2.1 Background

There is growing consensus that the gradual increase in global surface temperature is more than a long-term cyclic climatic phenomenon and that an anthropogenic, human-induced, influence is at work. While the increase has been low to date, 0.5°C to 2.0°C in the last century, current climate models indicate that the trajectory will increase over the current century. Six gases contribute to the so-called “greenhouse gas effect”, which is proposed as the main reason for climate changes. Of those six gases, carbon dioxide (CO_2), methane (CH4) and nitrous oxide (N_2O) are most abundant and influential. They are also the three greenhouse gases that interact with the terrestrial biosphere, soil and vegetation, which is either their source, sink or both. Worldwide, CO_2 from energy production, in particular from the burning of fossil fuels, provides the major source of CO_2. New Zealand is an exception to that rule as its strong agricultural base means that methane, derived from microorganisms in the rumen of sheep and cattle, is the greatest domestic source.

Climate change is a global problem that requires a global response. No country can escape its consequences and no country is too small to contribute to mitigation efforts. In New Zealand, while the expected warming will be less than the global average, the east of the country is expected to be drier and the west wetter. Adaptation to climate change impacts are important, and at least in the short to medium term some impacts, such as the ability to grow new crops, could be used to our advantage while others could be reduced if managed appropriately. The negative impacts that will eventuate to a greater or lesser degree include the availability of too much and too little water, changes in biodiversity, increases in biosecurity risks, and possible impacts on human health from new organisms, such as the Salt Marsh mosquito.

Mitigation is the only sustainable long-term option for managing climate change and, over time, for reducing greenhouse gas emissions from energy and agricultural use. To manage this requires the measurement and understanding of those changes in sources and sinks in the terrestrial biosphere that could capture greenhouse gases but that could also, without appropriate management, contribute further to the problem.

Part of the management framework will include the monitoring of carbon stocks in soils and forests. Management of the plantation forest estate of quick-growing exotic trees has meant that mechanisms are already largely in place to capture the changes in stocks in those forests. The same could not be said for our indigenous forest estate or for the carbon stocks in soils. Previous partial inventories had been made over the years for research and management purposes but no comprehensive long-term monitoring programme has been in place that would have helped managed for mitigation or report on our greenhouse gas stocks or fluxes in the national or international arena.

Despite the lack of a continuous monitoring system, a number of building blocks had been assembled over the years, often fortuitously as a by-product of biodiversity or primary production research and management. The foundations of a comprehensive carbon monitoring system were therefore already laid, albeit often well buried in notes, files and databases of scientists from current and previous eras. Using this template, a monitoring system has been designed for carbon that can be expanded to incorporate not only any the national land-based monitoring needs, but also, if required, other environmental monitoring needs.

2.2 Policy context

The policy context behind the need for a national carbon monitoring system began in June 1992, when New Zealand signed the United Nations Framework Convention on Climate Change (UNFCCC), which was ratified in September 1993 and came into force in March 1994. The commitment of the UNFCCC is to reduce CO_2 emissions to 1990 levels.

Article 3.3 of the UNFCCC states:

> 3. The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse gases and adaptation, and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties.

It is noted here that sources, sinks and reservoirs of greenhouse gases are required to be monitored as a part of determining policies and measures to mitigate the adverse effects of climate change.

Article 4.1 states:

> 1.... All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:
>
> (A).... Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;
>
> (b).... Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate

> change by addressing anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change;
>
> and
>
> (d)....Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems.

These clauses require the development of systems to enable data to be collected to meet the reporting requirements in the ratified UNFCCC.

For New Zealand this has meant developing appropriate systems to monitor and report on changes in the carbon pools in soils, forests and scrubland.

The Carbon Monitoring System for (indigenous) forests, scrublands and soils has thus been designed to enable New Zealand to meet its commitments under the UNFCCC and to begin the more robust monitoring required under a ratified Kyoto Protocol.

2.3 Kyoto Protocol

Under the Kyoto Protocol, certain human-induced activities in the land-use, land-use change and forestry sector that remove greenhouse gases from the atmosphere (known as carbon "sinks"), namely afforestation, reforestation and reducing deforestation, may be used by Annex I Parties (mainly the industrialised developed countries, including New Zealand) to offset their emission targets. Conversely, changes in these activities that deplete carbon sinks (e.g., an increase in deforestation) will be subtracted from the amount of emissions that an Annex I Party may emit over its commitment period. The scientific uncertainty and complexity surrounding the land-use, land-use change and forestry sector (known as "LULUCF") mean that the implementation details of these provisions need to be worked on further. Articles 3.3 and 3.4 of the Protocol consider the possible sources and sinks of greenhouse gas emissions that will be considered for reporting purposes.

The main points at stake are:

> **Defining "afforestation, reforestation and deforestation":** While Article 3.3 includes these activities in the scope of the Protocol, it does not define exactly what they encompass. As no common definition of these three terms currently exists, Parties must negotiate an agreed definition that will be used under the Protocol.
>
> **Additional human-induced activities:** Article 3.4 states that additional human-induced activities in the agricultural soils and LULUCF categories may be added to the three already counted under the Protocol. Parties now need to consider criteria for including new activities in the scope of the Protocol, and which activities should be selected.

A further important task for Parties is to **devise guidelines for reporting on the LULUCF sector** as part of the greenhouse gas inventories of Annex I Parties under the Protocol. In addition, Article 3.7 allows Annex I Parties to include emissions from land-use change in the calculation of their baseline (mostly 1990) if the land-use change and forestry sector were a net source of greenhouse gas emissions for them in 1990. Parties must decide exactly how this provision will be implemented.

Given the particular need for scientific advice on this issue, the IPCC agreed, following a request by SBSTA 8, to prepare a Special Report on LULUCF.

At COP 4, Parties agreed that COP/MOP 1 should take decisions on the two key issues outlined above, and that the COP would recommend such decisions after the IPCC Special Report had been completed and considered by the SBSTA. At COP 5, Parties endorsed a work programme and decision-making framework on LULUCF to enable these draft decisions for COP/MOP 1 to be recommended at COP 6.

Work has also continued inter-sessionally, with SBSTA workshops on LULUCF held in Rome on 24–25 September 1998, in Indianapolis, USA, on 26–28 April 1999, and in Poznan, Poland, on 10–15 July 2000.

2.4 Latest developments to December 2001

The Intergovernmental Panel for Climate Change (IPCC) Special Report on Land-use, Land-Use Change and Forestry was formally presented to SBSTA 12 in June 2000.

At SBSTA 13 part I (Lyon, September 2001), Parties worked on a "consolidated synthesis of proposals" prepared by the SBSTA Chairman. The outcome was a document (FCCC/SBSTA/2000/10/Add.2) that included elements for a draft decision, and an annex containing draft text on definitions, eligibility of activities under Article 3.4, accounting, measurement, and reporting. Parties invited the Chairman to develop further the annex to this document for consideration at SBSTA 13 part II in The Hague in November 2000.

In Lyon, the SBSTA also considered country-specific data and information on the LULUCF sector submitted by Parties according to a standard format agreed at SBSTA 12. The SBSTA urged Parties that had not yet submitted complete data to do so by 1 November 2000.

An informal consultation on LULUCF was held in Viterbo, Italy, on 9–11 October 2000.

Negotiations continued in The Hague in November 2000, first at SBSTA 13 part II (in the first week), then at COP 6 (in the second week), with the aim of adopting a decision on LULUCF at COP 6.

COP 6 in The Hague, however, was suspended, and was reconvened in July 2001 in Bonn to conclude the work set down for COP 6. The resumed COP6 held at Bonn from 16 to 27 July 2001 reached political agreement on a number of outstanding matters in the Kyoto Protocol but did not complete all work on land use, land-use change and forestry. A draft decision from COP6 was forwarded for adoption to COP7 held in Marrakesh, Morocco, between 29 October to 9 November 2001.

Sufficient agreement was gained at Marrakesh for the development of the Kyoto Protocol to continue and for New Zealand to consider its ratification in the latter half of 2002. An intense process of consultation begun in late 2001.

2.5 Implications of a non-ratified Kyoto Protocol for the Carbon Monitoring System

While a ratified Kyoto Protocol would add further support for the CMS, it is not the reason for it. The reporting of annual emissions and removals is already required under the UNFCCC and in the land-use change and forestry sector New Zealand has not been fully reporting because it does not yet have in place the data collection systems to do so. The operational CMS will enable New Zealand to meet its obligations under the UNFCCC more fully and to prepare better for the more rigorous future accounting requirements that may follow resolution of outstanding issues in the international negotiation process.

2.6 Science setting

Several Crown Research Institutes (CRIs) and Universities work in the area of climate change and greenhouse gas research. To develop the carbon monitoring system the two organisations with the most experience in forest production and indigenous management and soil science were engaged because of their expertise, their holdings of relevant databases, their access to other as yet uncollated data, and their current contributory research.

A 5-year working relationship began in 1995 between Landcare Research, Forest Research and the Ministry for the Environment. The Ministry for the Environment funded the work through the Green Package and worked with a Steering Committee that included representatives from the Department of Conservation, Ministry of Agriculture and Forestry and, originally, the Ministry for Research, Science and Development.

Databases were assembled, Geographic Information Systems (GIS) layers and maps produced, a number of reports written, and papers published in the international literature. Although some blind alleys were entered and often deliberately tested along the way, the final path became clear and was subjected to international panel scrutiny and review.

Review comments were addressed in the final 2 years' work and an operational carbon monitoring system delivered to MfE in 2001 that was intended to go operational shortly afterwards. While the core system is essentially in place, it remains to be seen whether the full potential of the system is achieved through its integration with other monitoring requirements, both within MfE and in other Government organisations.

3. Developing the 1990 Baseline for Soils

3.1 Conceptual framework

1990 is accepted as a baseline against which to measure changes in carbon stocks in the future. Therefore determining this baseline for both soil and indigenous forests is an important starting point for this project.

The work carried out in developing a baseline carbon stock was built on previously published work (IPCC 1996; Daly & Wilde 1997; Newsome & Willoughby 1997; Leathwick et al. 1997; Scott et al. 1997; Tate et al. 1997a), the main limitation of which was that the estimates of soil carbon took no account of land use. As land use, together with soil type and climate, is a key driver of changes in soil carbon, this project, based on the IPCC default methodology, used these three factors to stratify New Zealand for determining changes in soil carbon attributable to land-use changes.

The approach taken was to:

- establish how the New Zealand soil classification relates to that required by the IPCC
- determine land-use (vegetation) information for 1990
- determine the major climate layers for the country to be incorporated into a spatial framework
- supplement soil carbon (soil C) information for major soil groups not well represented in the initial inventory
- synthesise all available data in a GIS (geographical information system) format into major land use, climate, and soil types to provide a matrix of cells for the country.

Figure 1 illustrates the approach to determining the 1990 baseline and updating the carbon estimates for the monitoring system.

3.2 Reclassification of soil categories

New Zealand soils were reclassified into categories matched the IPCC guidelines, by cross-referencing with the National Soils Database. These were then used to produce a new soil data GIS layer. The following IPPC categories were included and Podsols was added.

- soils with high clay activity
- soils with low clay activity
- sandy soils
- Andisols
- Aquic soils
- Histosols

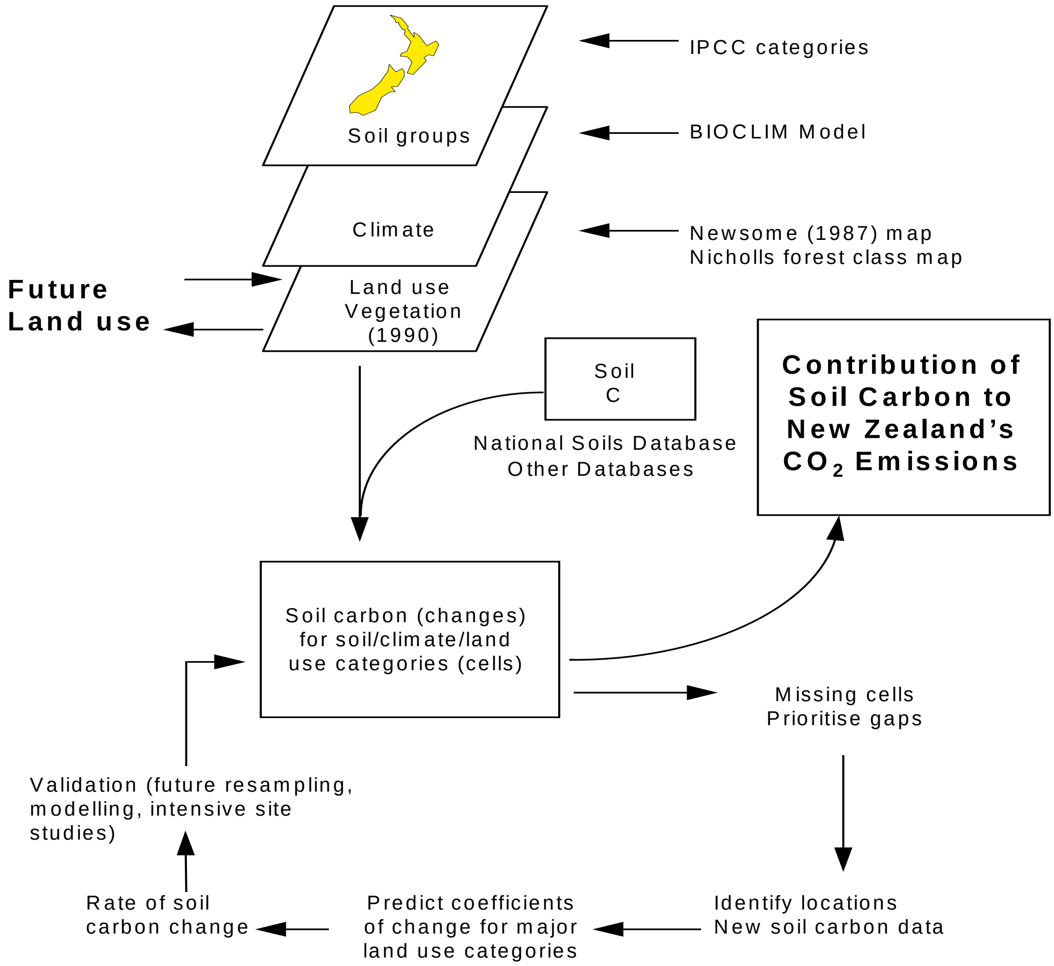

Fig. 1 Framework for assessing the contribution of soils to a national carbon budget

The IPCC guidelines specified the depth range of 0–0.3 m for reporting on changes in soil carbon. We have separated this depth range into 0–0.1 and 0.1–0.3 m to enhance our ability to detect soil C changes. Soil C in depth range 0.3–1 m is also reported when this is available.

3.3 Land information

Soil disturbance through land use can have a marked effect on soil C. Land-use practices can enhance soil C but, in general, many farming practices cause soil C to decline. A steady state eventually occurs when soil reflects its final level under the management practices in place. Land-use information for this project was originally derived from the 47 Vegetation Cover Classes in the Vegetative Cover Map of New Zealand (VCM) (Newsome 1987). The categories were reallocated into those appropriate for soil C monitoring, and include:

- Alpine
- Arable cropland
- Bare ground
- Exotic forestry
- Horticultural land
- Indigenous forest (conifer)
- Indigenous forest (broadleaf)
- Indigenous forest (mixed broadleaf/conifer)
- Improved pasture
- Unimproved pasture
- Scrub

As the VCM will not be updated, future carbon monitoring will need to be updated through an ongoing land-use database such as the Land Cover Database (LCDB).

3.4 Climate data

A climate GIS layer used interpolated climate data (Hutchison 1995), which combined data on precipitation and soil class to give soil moisture classes, which were combined with temperature data to give the following temperature/moisture classes:

- Boreal
- Humid boreal
- Very dry temperate
- Dry temperate
- Moist temperate
- Humid temperate
- Aquic

Soil type and climate combined gave 49 categories, which were reduced to 18 and combined with land use to give 198 categories, only 147 of which existed in New Zealand.

By amalgamating very minor categories and removing those combinations that did not exist, the number of cells was reduced to 39, which accurately categorise about 93% of the New Zealand landscape.

3.5 Results

At the end of the 1998/1999 year, once all the new data had been incorporated into the database, the soil C figures at the three depths were revised. Only one climate/soil/land-use class that exceeds 10 000 km^2 remains unsampled. As this class contributes 35% to the error variance, it remains a high priority for future sampling.

The revised 1990 national soil C estimates are now 1148 ± 49.5 Mt for 0-0.1 m, 1413 ± 80.0 Mt for 0.1-0.3 m and 1631 ± 193.0 Mt for 0.3-1.0 m layers.

4. A National Monitoring System For Soil Carbon

4.1 System requirements

While forests may appear to be the most observable form of terrestrial carbon accumulation, soils are the major terrestrial carbon reservoir, the functioning of which can be disturbed in a variety of ways, predominately through land-use change and land-management practices.

As previously described, the monitoring system for soil carbon is based on the IPCC (1996) default methodology, default and follows the method used to update the 1990 baseline for soil C, and referred to in Figure 1. The country has been classified according to a matrix incorporating soil type reclassified to the IPCC guidelines, climate and land use. Soil C is determined for three depth increments: 0–0.1 m, 0.1–0.3 m, and 0.3–1 m (Tate et al. 1997b).

The monitoring system is required to operate over a repeat period of about 10 years, in which time land use is likely to be the only major influence on soil C. Hence, any future monitoring system should be designed to capture those changes in soil C brought about by a change in land use. A system based on updating land use and applying land-change factors, known as coefficients of change (COC) is likely to be less costly than a plot-based sampling system providing there is a method to determine land-use change and providing the coefficients of change can be determined. If that were not to be the case, a plot-based sampling system, whether random or targeted, would need to be applied to the three-dimensional national soil matrix.

An integrated soil monitoring system could also include indicators of soil health and quality, of which carbon is only one indicator. Monitoring soil C will not only be important from a reporting viewpoint, but could also feed into policy relating to land management.

Other systems were examined that considered the following:

- the statistical uncertainty in estimates derived from a particular sample size
- the sample size necessary to achieve a desired degree of accuracy
- the cost of obtaining such a sample size
- the limitations and assumptions inherent in the estimation, and
- whether the result will answer the required question.

In particular, we considered:

- National sampling of key cells or land-use categories. The cost of this sampling strategy at the 95% confidence level is estimated at ~$160,000 per year for field sampling alone. It would be difficult under this system to attribute any change in soil C to a specific change in land-use activity and, according to the current IPCC guidelines, it would be difficult to determine whether such a change was anthropogenic

- Periodic sampling of key cells or land-use categories. Such a system would be intensive and costly, and changes to soil C could take up to 40 years to reach steady state before the full contribution from land-use change would be available.

- Updating national soil carbon estimates based on land-use change The cost of such a system is mainly associated with updating the land-use database, an activity necessary for the forest and scrub monitoring system and therefore to some extent a sunk cost of the overall system.

4.2 Predicting national soil carbon from process-based “soil carbon” and associated models

Several models have been produced that can predict changes in the soil C pool. They can provide a temporal dimension to changes in soil, and have generally been extensively validated using long-time-series data. It is envisaged that they would complement and enhance the utility of the coefficients of change system under development.

4.3 Designing the monitoring system

The most robust strategy would be to have a combined system of direct sampling, modeling and using coefficients of change, by making the primary estimation of soil C change attributable to land-use change from historical and contemporary data, and to compare these estimates with those from paired sites, models, and multi-temporal sampling at benchmark sites. The number of sites required will depend on the importance of the temporal component. It is likely that at least a partial network of new sites will need to be established.

Based on the above, a number of studies were carried out to:

- test the robustness of the three data layers
- provide a temporal component to the coefficients of change (COC)
- assess the contribution of benchmark sites to the monitoring system
- test the capability of the system to explain the variance in soil C at the landscape scale and quantify the effects of land use and land-use change.

4.4 Testing the system

Three tests on the monitoring system were carried out during 1998/1999.

Benmore Range in Central Otago was the site used to compare soil C values predicted by the monitoring system with those determined by intensive sampling. The variable being considered was climate. Soil C was measured from 72 locations in the Range with various combinations of aspect, elevation, and precipitation. The total soil C derived by sampling and testing was 1.2 Mt C. The proposed monitoring system estimated a level of 1.6 Mt C, reasonably close to the value based on direct measurement considering the large difference in scales between these two approaches. The higher value determined by the monitoring system was considered to be due possibly to the lack of information on slope and aspect in the model.

Our soil C estimates were compared with those based on the FAO soil attribute and extent information. This uses FAO-UNESCO soil maps of the world produced at a scale of 1:5 000 000 for which New Zealand has been assigned 17 soil types. The resulting analysis estimated 1207 Mt C in the 0–0.1 m layer and 1489 Mt C in the 0.1–0.3 m layer. This compares with the monitoring system estimates of 1208 Mt C and 1532 Mt C respectively.

The last test compares soil estimates from the monitoring system with those based on default IPCC soil C values, different soil/climate categories, and some land-use coefficients. Comparison of the default values with New Zealand mean soil C values for the same soil/climate categories show that New Zealand soils are generally higher in soil C stocks then global estimates (Tate et al. 1997b).

5 Development of Baseline 1990 Estimates for Forest and Scrub

5.1 Methodology

Indigenous forests are a major carbon reservoir in New Zealand. The approach adopted for this study is to determine a suitable classification system for forest and scrub along with the necessary biomass relationships, and then apply the biomass figures to the total extent of each forest type, i.e. allometric equations for biomass, for the country.

To obtain the extent of total forest by forest and scrub type, a number of available databases were examined and allometric equations for biomass refined from biomass studies.

Fine-scale maps of indigenous forest in New Zealand before this study are scarce and often confined to small areas. The most comprehensive map set of both the distribution and composition of primary indigenous forests throughout New Zealand is the 1:250 000 forest class (FSMS6) that recognises 18 forest classes. These maps were produced before 1990 and needed substantial updating and additional coverage and were therefore not used to produce a 1990 baseline.

A previous study that produced the Vegetation Cover Maps (VCM) has national coverage for all woody vegetation but has been compiled at a scale of 1:1 000 000. Therefore, although it manages to resolve major plant communities, it only delineates map units greater than 500 ha.

Another key spatial database was the National Vegetation Survey (NVS) that contains data from plot-based studies collected on vegetation from 7083 plots around the country.

Hence to determine a 1990 baseline for indigenous forest and scrub, data were used from the NVS, relationships were made from a few biomass studies, and area data from the VCM used to generate a forest estimate for total biomass carbon stored in live trees. We selected 574 plots that were as geographically dispersed as possible and had minimum bias in terms of regional sampling intensity, elevation, and mean annual precipitation.

5.2 Results

We estimated 1990 forest biomass carbon as 919, 939, 943, and 932 Mt, based on pooling the data from all 574 plots and stratifying these sample plots by VCM classes, elevation classes, and mapped soil-climate strata, respectively. At most these estimates differ by 2.6% and have a mean of 933 Mt. Of the national forest biomass carbon reservoir, 60.0% is stored in beech trees, 26.7% in other hardwoods, 13.2% in conifers, and 0.1% in other (e.g., tree ferns) taxa. The standard error of the national forest biomass carbon estimate is ± 25.1 Mt. The estimate of biomass carbon in scrub and other woody mixtures of indigenous vegetation were calculated as 527 Mt. (Goulding et al. 1998).

Tate et al. (1997a) estimated total standing stock of indigenous forest litter carbon as 570 Mt. All estimates are very sensitive to the actual size of the mapped area and heterogeneity within VCM classes.

6 Monitoring Carbon in Indigenous Forests and Scrub

6.1 System requirements

Indigenous forests cover approximately 6.4 million ha of land in New Zealand. Contrary to the trend in recent history when bush was cleared and burned for farming, some land now recognised as economically unsustainable for farming, due to poor soils, steep slopes, or low commodity prices, is being left to revert to its original land cover. It progresses through a succession of bush eventually to mature forests. Indigenous forests, with their large biomass, form a reservoir for carbon, second only to soil.

There are, however, several forces acting on the extent of the forests and the amount of biomass and therefore carbon they contain. In part, as well as the natural reversion of pasture to scrub and, eventually, mature forests, our indigenous forests are under attack from pests such as possums, wild goats, and deer, and are subject to catastrophic events and limited harvesting. In short, the indigenous flora of New Zealand is in a state of flux, even without active forest clearance or large-scale planting. It is still debatable whether all these effects are ultimately classified as anthropogenic and therefore included in the Kyoto Protocol. However, the individual processes that contribute to forest biomass or carbon quantity changes need to be monitored so that we can understand and protect them, as required by the Framework Convention for Climate Change.

In considering the carbon balance of indigenous forests it is necessary to examine the entire ecosystem including the soil and the coarse woody debris that has fallen to the forest floor to form litter. Fine litter is dealt with as part of the national soil monitoring system, but coarse litter with a diameter greater than 10 cm has been included as part of the forest system.

As well as biomass or carbon accumulation, it is also sensible in any monitoring system to consider other values inherent in those forests. The members of the Steering Committee for this project add policy and management perspectives relating to biodiversity, forest condition, pest management, ecosystem processes and risk assessment. Considerable research within the central-government-funded PGSF has, and is, being carried out. This links directly or indirectly to this project, and science providers are strongly encouraged to ensure their research programmes contribute to the operational needs of the proposed monitoring system.

The baseline level of carbon stocks in indigenous forests is as reported for 1990, and a monitoring system needs to estimate the change in that figure and pull apart the various contributions to that change. The system must be quantitative and give estimates of uncertainty, the goal being to achieve the 95% confidence level. Any change in that level of uncertainty would influence the amount of direct sampling required and therefore alter the cost of the system. The system needs to be appropriate to the New Zealand situation and will not necessarily mirror systems used in other countries with different land uses and management practices. In particular it needs to incorporate regenerating scrub.

6.2 Consideration of alternative approaches for the monitoring system (Landcare Research New Zealand Ltd & Forest Research Institute Ltd 1998)

There are four distinct approaches to the monitoring system and various permutations of their combinations. They vary in the technology available, their cost, and their ability to incorporate the non-carbon attributes required of the system.

The simplest and probably cheapest system is recommended by the IPCC for a tropical, undeveloped third-world country where carbon density is estimated for shrubs and for closed forest. Changes in carbon density are determined to be directly proportional to land areas in either of those two categories. Such a system would require an updated Land Cover Database that monitors the extent of land in different land uses over time.

A simple plot-based sampling system could be used to give information specific only to the international reporting requirements without assessing other information on changes within the forests, or attributes relating to forest health and biodiversity. It would involve forest extent estimated through an LCDB with limited plot sampling of about 400–500 plots randomly distributed across New Zealand. For the requirements of the current contract this would be the preferred option. However, it would have to be modified to include the wider requirements of other stakeholders.

Remote-sensing techniques show promise and can clearly be used to estimate forest extent, but further precision in determining forest classes and estimating changes within indigenous forests is still under development. This option will become more available as technology develops, and may in time be able to substitute for some plot-based monitoring. The degree to which this occurs will eventually depend on what non-carbon values are incorporated into the CMS. (Ranson et al. 1997; McNeil et al. 1998; Stephens et al. 2001)

The most comprehensive approach is to follow a model used in the Northern Hemisphere that would enable changes in carbon levels to be estimated along with information for key stakeholders interested in other forest attributes. The method uses a LCDB to measure forest extent, but then uses a comprehensive plot-based system to consider forest and scrub attributes. The plots would be located by a systematic random sampling regime across the country but would be precise enough to give information at a range of spatial scales and geographic, ecological, and regulatory boundaries. The information products of this system would anticipate multi-stakeholder requirements into the medium future and be on a par with other first-world countries.

Each of the above systems could be supplemented with simulation models that provide future predictive capability of productivity and biomass accumulation under different scenarios. These models are being developed within PGSF research programmes.

6.3 Designing the monitoring system

For the 1990 baseline carbon estimates for indigenous forest, 574 plots (20 × 20 m) from throughout the country were selected that were as geographically dispersed as possible and with minimal geographical and climatic bias. It has been assessed that if 95% confidence is to be achieved, any stratification of the forest should not reduce the number of sample plots. This number may need to be increased if other features or management outcomes, such as pest control, were to become part of the purpose for the monitoring system.

Testing for forest vegetation was carried out within a grid of 9 × 9 km, superimposed over the LCDB vegetation map within a South Island that had good historical data, during the summer of 1998/1999. This created 62 sampling points, 39 in forest and 23 in scrub. It gave the same 95% confidence level as had been proposed for the overall system. The sampling intensity was based on procedures used extensively for NVS sampling and used to calculate the 1990 carbon baseline, providing data to answer the following stakeholders needs:

- woody biomass as an indicator of carbon
- tree death by species as an indicator of forest health
- regeneration by species as an indicator of forest maintenance
- invasions of exotic plant species as an indicator of intactness
- browsing by introduced animals as an indicator of animal impacts
- live and dead stem biomass as a habitat indicator
- rare and threatened plants as an indicator of diversity maintenance.

To obtain a figure for biomass per hectare, the collection of biomass data was the prime consideration. A network of permanent plots (20 × 20 m) was proposed as the basis for the monitoring system and, where possible, existing NVS plots were to be used.

In addition to sampling methodologies for forests, sampling methods for scrub, which until now had not been well defined, and sampling procedures for coarse woody debris on the forest or scrub floor, were also required. Understorey (i.e. seedling samples) was identified and measured within each subplot.

6.4 Calculating carbon stocks

The work in the transect provided an opportunity to test the feasibility and accuracy of methods being developed to determine carbon stocks. Previous biomass studies from destructive sampling contributed to relationships between forest measurements, biomass, and carbon content. Refining the regression equations derived from those studies was a recommendation of the study, particularly for those species that composed over 95% of the forest carbon stock (Allen et al. 1998).

A volume-estimate approach to determining scrub was used that involved destructive sampling of two bushes from the side of each scrub plot.

Sampling of the transect estimated that 15% of the carbon in forests is from dead wood, but only 1% of the carbon from scrub is dead wood.

The study confirmed that around 500 forest plots would be required to estimate forest carbon at 95% accuracy. The same number for scrub plots would give ~90% accuracy. The mean carbon stocks per hectare were 203 t/ha for forest and 22 t/ha for scrub. Multiplying these figures by the estimated areas of forest and scrub gave carbon stocks of 67.3 and 2.9 million t respectively.

6.5 Estimating the spatial extent of indigenous forest and scrub

In any monitoring system, the extent of indigenous forest will need to be estimated through the updating of land-use databases that either focus on forests or include forests. The two existing databases considered the best candidates for this task were the Vegetative Cover Map (VCM) and the Land Cover Database (LCDB). Plot sampling results in the transect were used to determine which of those two databases should be recommended for the monitoring system.

The study showed that the mapping scale of the VCM, at 1:1 000 000, gave rise to mixed land-cover classes that could not provide sufficient precision of location and extent for the monitoring system. In addition, the VCM is now over 15 years old and would need to be updated to represent recent land-use cover. The LCDB showed a high degree of accuracy in separating forest and scrub from other classes, but did not distinguish well between those two classes. This deficiency was not considered a problem for the monitoring system where both classes can be treated as one population. The recommendation from this study was that the LCDB be the primary mapping tool to determine the spatial extent of forest and scrub, with the VCM and a third classification system, known as the FSM6 series, being used to provide more detailed indigenous forest species information as required (Newsome et al. 1998).

6.6 Physiological modeling

There is scope to integrate physiological modeling into the system potentially to reduce the amount of sampling required, or to help target it better so that resource managers have a predictive tool to consider "what if" scenarios of climate variation or alternative management practices on forest condition and extent.

Work on these models is mainly being undertaken as part of PGSF programmes. When linked to remotely sensed information related to canopy condition and forest age, the programmes provide information on carbon uptake rates and biomass accumulation. This work will continue and will link strongly with plot-based work carried out in the development and implementation of the monitoring system so that over time it becomes an integral part of the system.

6.7 Data handling and management (Gibb et al. 1998)

An essential part of any ongoing monitoring system is the analysis and storage of data. The requirements for the forest and scrub component of the overall system were:

- a computer system capable of inputting field measurement data, analysing it to calculate the quantity of carbon per hectare, and storing the plot data for future measurements
- a report detailing the data model, the potential to use existing systems, and the interactions with carbon-specific software.

The data file model for the South Island transect recorded 12 discrete types of data. Most were collected for biomass carbon estimation but some addressed other end-user needs. The data stored are:

- tree diameter measurements by species (Diam)
- seedling and sapling counts in subplots by species (Ustorey)
- site information and stand characteristics (Site)
- species composition and cover estimates (Recce)
- upper 10 cm of mineral soil chemistry (Soil)
- coarse woody debris in decay classes and, where possible, by species (CWD)
- tree diameters on 20-m-radius plot by species (>60)
- total height of representative trees (Height)
- estimate of woody cover of scrub at 25 point (Cover)
- width and height of individual scrub plants by species (Width)
- mass data of individual scrub plants (Width biomass)
- mass data from an area of scrub (Cover biomass)

To calculate the level of carbon stored in biomass on a forest plot, three biomass carbon values were calculated: coarse woody debris; trees on the 20 × 20 plot; and trees less than 60 cm on a 20-m-radius plot. The data files required were tree diameters, height of representative trees, and species.

In considering a system for forest carbon data, existing databases were reviewed. The closest existing systems were the NVS database and the production forestry permanent sample plot (PSP) system. The first system, NVS, is primarily intended to determine spatial and temporal patterns in indigenous forest composition and structure for the surrounding environment. It can be used for carbon estimates but also for a variety of other data, required for forest health and biodiversity management. PSP is mainly intended to determine the effects of alternative silviculture methods on production forest growth.

The data-management system for forests and scrub is only one part of the overall information system. Also required, either as a separate component or integrated with the forest information, is information on soils, and a delivery system that transfers the required information to the client.

7 An Information Management System for the CMS

7.1 System requirements

Estimating and monitoring carbon at a national level according to IPCC guidelines requires the assembly, analysis, storage, and provision of large amounts of base and derived data. To optimise that process, an efficient information system must be designed and put in place. In the development of the CMS, information was initially stored within existing or modified databases to provide a method of integrating and transferring data as required. The scope and scale of the monitoring system can vary considerably according to end-user needs, and the resulting system development and maintenance requirements will have a major bearing on costs. Clearly a system can begin with a simple framework and become more sophisticated as user need demands.

The five key features of the information system are:

- establishment of national datasets to monitor changes in carbon storage in indigenous forests and soils
- compilation of an inventory of existing datasets for changes in carbon storage in indigenous forests, scrub and soils
- recording of results and methodology from the development of the 1990 baseline of carbon storage
- management of data generated in the process of completing the development of the monitoring system
- development of data standards and a meta database of data and procedures (Gibb et al. 1998).

Additional requirements of the overall monitoring system that will have an impact on the information system are transparency, flexibility, and legal defensibility. These will ensure that the carbon estimates are accepted in the international community and that the requirements of other stakeholders in the monitoring system can be incorporated as required.

7.2 Proposed structure

The use of electronic storage and analysis is taken as a given, even if the system is simple to start with. It is important therefore that a common data platform and system architecture is developed and adhered to. Ideally, any other environmental datasets that may eventually become part of a larger, national, land-based, environmental monitoring system would also have the same platform. Given the links between the data in the CMS and other databases, in particular NVS and NSD, some distribution of the data is likely to occur. This would be more apparent if other environmental monitoring needs are

eventually added to the CMS so the ability to extract data through a common query language is seriously recommended for any potentially contributing dataset.
A blueprint has been developed that provides an overview of a proposed information system. This proposal provides a mechanism for widely distributing data to a variety of end-users and is the most comprehensive, complex, and costly possible option. It consists of:

- a custodial information system that records data collected by the monitoring system
- an analysis system that provides all the calculation and reporting functions of the system.

7.3 Custodial systems

Five individual data systems form the core of the Carbon Monitoring Information System (CMIS. They are:

- the data used to generate the 1990 baseline, which may be subject to refinement if new improved 1990 data become available
- inventory data from field data from forest and scrub sites and data to determine biomass
- information used in deriving soil carbon values by field sampling and modelling
- information on land cover derived from satellite imagery and land-cover databases
- meta-data that records information on all the datasets used in the monitoring system.

7.4 Carbon analysis system

The analysis system will:

- calculate the national reservoir of carbon for forest, scrub, and soil broken down by IPCC categories for the 1990 baseline
- calculate the national reservoir of carbon for forest, scrub, and soil broken down by IPCC categories for the monitoring system, by date of inventory
- provide results in a form acceptable to the IPCC
- calculate changes in carbon levels by IPCC categories for inventory periods
- provide for baseline maintenance and improvement
- provide for ad hoc queries.

The delivery system is yet to be finalised and will depend on end-user requirements, both for the carbon monitoring system and for other management and monitoring options, the organisation involved in providing the monitoring service, an agreement on intellectual property and access issues, the degree of sophistication required, and the acceptable price for the system.

7.5 Custodial systems

1990 baseline system
Collates and manages the 1990 baseline datasets, and allows modifications to those datasets as knowledge increases.

Forest and scrub
Will record the raw inventory data collected in the field for forest and scrub plots.

Soils
Will record data used in creating the soil cells and the data collected from field sampling, e.g., from soil pits and paired sites.

Land cover
Will record information about the land cover of New Zealand. The data envisaged are the VCM, FSMS6, LCDB and 5-yearly LCDB updates.

Meta-data
Records the meta-data at the series level of all the datasets used or referenced by the system. It comprises an Internet-based entry-and-query tool available to all users.

Management module and common query language
Provides an audit trail of the data stored in each custodial system. The common query language is a proposed standard for querying and extracting data from each database.

7.6 Carbon analysis system

The analysis component of the CMIS relies on the underlying custodial systems to provide both data and analytical functions. The analysis system will:

- calculate the national reservoir of carbon in the three target areas of indigenous forests, scrublands, and national soils, broken down by IPCC categories for 1990 from the 1990 baseline datasets, and allow for modification of data and functions, generation of audit trails, sensitivity and spatial analysis
- calculate the national reservoir of carbon in the three target areas of indigenous forests, scrublands, and soils, broken down by IPCC categories for other years based on data in the monitoring databases. This could use different methodologies from that required for 1990
- provide results in a format appropriate for IPCC chapter 5 reporting, though not necessarily using the workbook approach of chapter 5
- calculate changes in carbon held in the target areas between different inventory periods
- provide for baseline maintenance. Different baselines could be created at different times using different methods. Rather than recreating baselines, these can be stored with the meta-data describing fully the baselines. (Baseline in this context could be at any year)

- provide for ad hoc queries and integration of extended analysis functions, e.g., climate models.

The functional specifications, in the form of data flow diagrams, have been developed for the analysis system.

7.7 CD-ROM system

This system provides the following functions:

- integrates copies of all the datasets
- provides access to underlying data for use by other data management systems
- duplicates the Internet-based meta-data custodial system
- provides the framework for implementing the Carbon analysis system.

An authoritative version of this system will be created as required, from which duplicates for distribution to users will be made.

7.8 Gaps in knowledge

The options for a CMIS range from several entirely separate carbon data systems, each producing a carbon figure and nothing more but which can be added together to provide a carbon figure for the country, to a series of integrated data systems with a range of data, which can be used for many purposes and which is electronically available to a wide range of end-users to analyse, integrate, and interpret. The more complex the system, the more costly and difficult the technical and intellectual property issues become.

Much of the data that will contribute to the custodial systems comes from pre-existing databases. It remains to be determined which structure of the current systems will support the functions required of an integrated CMIS.

Some of the data needed for this system were originally collected for other purposes for various clients. The nature of the agreements required to provide the necessary level of access to, and subsequent use of that data, needs to be clarified. Having clarity as to which organisation or organisations will be responsible for maintaining the monitoring system will help determine the data access issues. Ownership and intellectual property issues are intimately linked to data access.

There are several issues relating to the distributed nature of the proposed system that need to be considered before that model is confirmed. The cost of such a system is not trivial and is unlikely to be covered by the funding available over the remainder of the life of the project. The fact that the custodial systems have different software means that, if they are to be distributed via the same delivery system, they must be linked by a common query language. How complex that is will also depend on the degree to which "carbon" is linked to MfE's environmental performance indicator system.

Practical, realistic, and specific end-user requirements need to be further refined before progress can be made in costing resource requirements for further development and ongoing maintenance of the CMIS. The intention is, within the CMIS, to collect data on soils, scrub and indigenous forests that would have enormous value for purposes other than monitoring carbon, including many aspects relating to the management of indigenous forests, carbon accounting, and land management through a consideration of soil quality. The consideration of the provision of data should ideally be in relation to the various government programmes, which overlap with the carbon programme. Once the preferred option has been selected, development of the core architecture of the CMIS can continue. This will consist of:

- a construction phase in which a beta model is tested (in relation to agreement on end-user needs and output functionality)
- installation of the beta release with user training and user manuals
- provision for upgrades and modifications.

8 International Review of the CMS Development

8.1 Terms of reference

In late 1999 an international review of the CMS was held, with particular emphasis on soils and forest and scrub components

The terms of reference of the review were to:

a) assess and comment on the robustness, scientific and technical merits and credibility of the approach and systems being developed and proposed by the research providers;
b) assess and comment on the overall consistency, compatibility and practicability of the approaches being proposed, keeping in mind the project's overall goal of a single national framework for monitoring C, and changes in C over time, as the basis for New Zealand's international reporting on land-use change and forestry and the FCCC;
c) identify and assess any gaps, issues and possible improvements that should be addressed in future work, including priorities and suggestions for possible approaches to address and resolve identified issues;
d) assess and comment on the robustness and versatility of the proposed approaches as a basis for monitoring other key indicators or parameters relating to sustainable forest management and land use, forest health and condition, and biodiversity; and
e) provide clear conclusions and recommendations for future development of the framework and national monitoring system.

8.2 Members of the review panel

- Dr Margriet Theron (chairperson), Dean of the Faculty of Forest and Technology at Waiariki Institute of Technology, Rotorua.
- Dr Sandra Brown, Senior Programme Officer, Forest Carbon Monitoring, at Winrock International, Oregon.
- Dr Colin O'Loughlin, a forestry consultant from Christchurch.
- Dr Keith Paustian, Natural Resource Ecology Laboratory at Colorado State University, Colorado.
- Dr Andy Whitmore, Silsoe Research Institute, England.

8.3 Main conclusions (Theron et al. 1999)

The main conclusions of the review panel were:

1 Good progress has been made towards the development of a working CMS, but a lack of integration between the forest and soils programme has created potential problems.

2. The conceptual approach for monitoring soil C is a significant improvement on the IPCC methodology, but much work remains to be done to estimate and validate appropriate COCs should be a priority.

3. The conceptual approach for monitoring C stocks in vegetation is heading in the right direction. The use of a fixed grid and PSPs to estimate the C in the identified major C pools is sound and according to international practice, but the development of temporal COCs should be a priority.

4. For forests, the use of limited data for developing allometric relationships in live and dead vegetation remains a major problem.

5. The monitoring system needs a good, well-documented QA/QC system to lend it international credibility,

6. Accurate estimates of land-use change over time are fundamental to the CMS for indigenous forests, scrub and soils. The link between future land-use change and new sampling and data collection need to be further developed and integrated between the two programmes.

7. The approach in the forests programme appears to be more focussed on changes within the existing extent of forests and scrublands, and insufficient attention has been paid to the impact of future changes in land use and cover on the data collection strategy. The conceptual approach for the soils programme focuses more on the effects of changes in land use and insufficient attention has been paid to potential carbon stock changes in existing "stable" soil/climate/land-use classes.

   The overall programme has done a credible job of integrating existing data to arrive at an acceptable circa 1990 estimate of carbon stocks in indigenous vegetation and soils.

8. For a long-term monitoring programme, the retention and maintenance of research capacity is of concern. The programme is currently vulnerable to the loss of individual scientists.

9. The international credibility of the research underpinning the development of the monitoring system would be enhanced by further publication in peer reviewed literature, for both forests and soils.

10. On-going and assured funding for the CMP, and especially funding to enhance the programme in the ways recommended by the review panel, are of concern. More co-ordination among research providers and stakeholders will help to ensure optimum application of scarce resources.

11. The national CMS has the potential to provide a foundation for supporting other monitoring and research programmes, from local through to national level.

8.4 Priority list of recommendations

The review panel's recommendations, taken from earlier chapters of this report, are repeated below. The recommendations have been grouped and prioritised.

Table 1 Recommendations of highest importance and highest priority for implementation

Recommendations of highest importance and highest priority for implementation	
Financial aspects	1. The management and funding of the CMS should be adjusted to enable continuity of research effort, and earlier assurance of funding for each financial year. 2. An accurate estimate of all costs (fixed and variable) of the monitoring system options should be made as soon as possible.
Spatial Aspects (LCDB etc)	3. It is critical that the classification developed for the next iteration of LCDB meets the needs of both the soils and the forest and scrub inventories, as well as other stakeholders where possible. Acquisition of a ground-receiving facility, which has apparently been discussed repeatedly in the past, should be seriously (re)considered to insure maximum data availability and timeliness.
Field Sampling / Monitoring	4. A method for estimating C stocks and their changes at varying levels of desired precision in different LC/LU classes, and the implications for cost, need to be addressed. 5. Explicit evidence should be provided that the researchers have given consideration to monitoring disturbance effects, how important these effects are to C stocks, how their plan addresses this or what additional data need to be collected to incorporate this into the plan. 6. Researchers should identify areas where active tree harvesting in indigenous forests is taking place, and spend time there destructively harvesting and measuring, using standard techniques, a selection of trees to obtain the necessary biomass data for the development of allometric equations. 7. The ongoing monitoring system should address which LU/LC classes and C pools need to be monitored, over what time frames and at what scales. 8. Opportunities to leverage the additional costs of more widespread soil sampling through collaboration with other programmes such as soil quality investigations, should be pursued. After a full remeasurement period, the data would be invaluable as a validation of the soil C change estimated based on COC.

	9. Provisions need to be made, with explicit plans, to account for the recruitment of new forest and scrub areas (e.g., via pasture abandonment) as part of the grid-based forest and scrub monitoring procedures.
Quality Assurance Aspects	10. A QA/QC plan should be developed for future implementation, and all field, laboratory, and analytical techniques should be coordinated among the various research teams, to add credibility to the CMS. 11. QA/QC procedures should be defined and implemented, including field sampling, sample preparation (sub-sampling, grinding), and C analysis (analytical standards, blind checks).
Land Use Changes	12. Existing land-use statistics should be explored as an auxiliary source of information on historical land use change (i.e. land-use history) in relation to the soil C monitoring programme. 13. Efforts should be made to establish benchmark sites, particularly for land-use types that are expected to undergo significant changes, e.g., abandonment of pastures. One option that might be explored is to locate very recently abandoned lands as potential benchmark sites.
Meeting the needs of stakeholders	14. The future monitoring programme needs to find a balance between the needs for C and the needs for other environmental variables – all stakeholders should develop a minimum list of needs. 15. Closer communication and cooperation between the CMS researchers and DOC regarding forest, scrub and soil monitoring could enhance the contribution of the CMS to the development of environmental performance indicators.

9 Response to the Review

9.1 Key issues to be addressed

A workshop was held in March 2000 involving key stakeholders and scientists. It addressed the key review issues so that over the following 18 months the science team was able to concentrate on responding to the recommendations of the review committee and producing an operational carbon monitoring system.

Immediate issues that were addressed included:

- the initial documentation of protocols, in particular QA/QC
- quantifying future soil carbon changes
- initiating work on the integration of the forest, scrub and soil components within the framework of the LCDB
- improving allometric relationships for individual tree species, biomass and hence vegetation carbon content.

In the final year of the project the following components were completed:

- Definition of on-going research needs
- Final framework documentation and a presentation on the project
- Cost estimates for the operational system
- All specifications for the final working system
- Development of the reporting tools
- The unifying of the soil, forest and scrub components through the LCDB
- Improvement of allometric relationships
- Estimation of coarse woody debris and decay status in vegetation and its contribution to carbon budgets
- Consideration of sampling strategies, with an explicit component concentrating on new forest and regenerating scrub
- The testing of further sampling options
- The testing of soil estimates considering new variables, which include slope and aspect, and integrating the digital terrain model with the generalised linear model
- Consideration of the effect of land-use history on coefficients of change
- Consideration of a range of issues relating to further soil sampling requirements.

9.2 On-going research needs (Allen 2001)

Rationale

Although the CMS can be implemented with the information and methodologies currently available, it can be improved. There is a need to define and reduce current error estimates, to provide alternative methods to validate and verify the carbon estimates, and to meet other stakeholder needs in the most efficient and effective manner. The Research needs can be addressed through a combination of operational research within the CMS and underpinning research within the FRST portfolio. As a key stakeholder in environmental research, MfE's underpinning needs for greenhouse gas reporting should be a priority for them.

LCDB related issues (Stephens et al. 2001)

The report of the international review panel (Theron et al 1999) recommended that every effort be made to develop a reliable base line as close to 1990 as possible. Sampling of aerial photography and satellite imagery could be used to quantify land-cover change between 1990 and 1996 to a known accuracy. These changes, when combined with the LCDB, could generate a 1990 picture of land cover. Thereafter, the soil CMS Generalised Linear Model (GLM) and an equivalent regression model of indigenous forest and scrub carbon could generate a 1990 carbon budget. There was also a requirement to reduce the over-estimation of bare ground from the LCDB and delineate arable cropping areas in the LCDB.

There are therefore two major tasks for future mapping research. One is to define classes, or other measurements, that describe land cover/land use characteristics that are important to soil and vegetation CMS concerns, while recognising that, these must fit currently into the existing mapping framework (LCDB). The second task is to develop methodologies for detecting and describing these classes of interest, using remote sensing imagery and any other relevant sources of information. To meet the needs of this large-area, frequent-update-mapping exercise, these new methodologies must be highly automated, and the classes or measurements chosen must be amenable to automated discrimination. There are two generic needs for any land-use change detection method. One is that the method should be as automated as possible, for objectivity and efficient operation over large areas. The other need is for documentation accompanying the spatial database, specifying its purpose, limitations and accuracy, and defining its constituent classes or measurements with the methods used to obtain them.

Land mapping

Even using multiple visual cues, some land uses will require knowledge of temporal dynamics for discrimination. This may take the form of in-depth knowledge of timing and rotation of farming practices in a certain region so that image acquisition can be carefully scheduled for critical periods when crops to be separated are at different stages of canopy development. A second example could be a carefully timed image acquisition for direct spectral observation of soil pugging by cattle in wet conditions during the winter. A multi-temporal sequence of imagery can provide even further discriminating power, to track the flush and senescence cycles of different crops.

The uncertainty in measured forest and scrub carbon density far outweighs uncertainties in their mapped area (Stephens et al. 2001). These uncertainties are related to the number of scrub (and forest) plots used in the analysis. More plots, especially of scrub, could reduce this uncertainty to a degree, but regression of carbon density on climate layers should also be researched.

Biomass calculations

Further work on allometric relationships will be required including seral vegetation types. Mapping of land use and land-use change is a complex task, and is an area of active research in the international remote-sensing community.

Refining the scrub methodology

The methods used in the CMS for forests have been commonly applied to understanding spatial and temporal variability in forest biomass, while the methods proposed in the CMS for shrub-lands have not been widely used and have received little testing. Within the MfE carbon project the emphasis again remains on further testing and developing the CMS for forests. Notwithstanding this, the international review panel called for explicit plans to account for the recruitment of new scrub areas (e.g., via pasture abandonment). This is because of the recognition shrub-lands may receive in accounting for carbon sequestration as a consequence of changes in land use under the Kyoto Protocol.

Estimating and validating land-use effects on soil C (Wilde et al. 2001)

The soil CMS has been developed to allow the direction and likely magnitude of soil C changes from land-use changes at a scale of 1:250,000 to be assessed. It is based on the IPCC default methodology, and uses an efficient stratification of the land area by soil type and climate, with an additional factor (rainfall x slope) introduced to explain a significant fraction of the residual (within soil climate and land use categories) variance in soil C. This additional factor is a surrogate for the effects of soil erosion. Currently, major disturbance effects (e.g., erosion, drainage of organic soils) are not considered in the soil CMS.

The major land-use changes in New Zealand currently, and in the foreseeable future are: pasture-to-planted forest; low fertility pasture-to-scrub. A realistic time frame for directly monitoring soil C changes resulting from these land-use changes would require repeat sampling at, e.g., 20-year intervals, too long to be of practical use for international reporting. Furthermore, a direct monitoring approach involving more frequent (e.g., 5 years) remeasurement of soil C at fixed points is impractical for the soil CMS; monitoring the effects of key land-use changes on soil C at carefully selected benchmark sites can, however, be useful for testing and validating the soil CMS. Accordingly, soil C changes for key land-use changes predicted by the soil CMS will need to be validated by remeasuring soil C using paired (benchmark) sites, where soil C measurements were made at the time of the land-use change. Over the next 5 years, process-based models will increasingly be used to indicate the trajectories of these soil C changes over an appropriate time scale (e.g., 20 years), from which more accurate annual changes can be calculated.

Disturbance

As there will be a gap of several years between sampling any particular site, local periodic disturbance could occur without being detected. A method to predict disturbance would therefore be worthwhile. It is suggested the most critical disturbance agents on which to focus on in New Zealand from a carbon dynamics perspective are introduced herbivore impacts, land clearance, and the impacts of indigenous forestry. Some research is already being undertaken on how these disturbances impact on carbon storage, and we suggest MfE may need to fund further research in this area related to their specific operational concerns. There is also considerable other research on specific disturbance types that impact on forest structure. Because much of New Zealand is tectonically active, some recent research efforts have focused on earthquake impacts on forests, both regionally and locally.

From a carbon storage perspective, the development of our understanding of the impacts of earthquakes in Westland forests may help explain any trajectories in forest carbon storage emerging from the CMS.

Verification

Verification is intended to help establish and improve the reliability of inventories. Verification can be achieved in a number of ways. These include:

- Comparisons with other independently compiled national- or regional-scale estimates.
- Comparisons with inventories from other countries, which allows cross-checking of the assumptions used, the completeness of the inventory, and the overall approach.
- Derivation of estimates using different methodologies.

With the small size and limited databases in New Zealand, on-going verification should occur to increase the international acceptance of our estimates.

Long-term ecological research (LTER) sites

The rationale for LTER sites is that to developing an understanding of such a wide range of ecosystem processes, and their interactions, at many locations is difficult. In New Zealand there has been little support for such sites outside the scientific community – yet it must be more widely appreciated that such sites are essential for understanding the dynamics of ecosystems. This is the case for understanding carbon dynamics.

Benefits of LTER sites:

- invaluable for monitoring a wide range of ecological response to anthropogenic (direct or indirect) changes. They can provide experimental sites with documented land-use history and management. From a carbon perspective, time-series data can be used to quantify the rates of sequestration along environmental gradients following disturbance and to contrast the impacts of various forms of land management.

- integrating long-term monitoring with short-term experimental work provides insights into why long-term changes occur, and allows for the development of robust process-based models by integrating research results obtained over multiple time scales. For example, nutrient addition experiments are a useful way to test limitations on carbon sequestration rates under a range of conditions.
- long-term records are invaluable for validating model predictions over different time scales. Changes in soil carbon with land-use change occur over years to decades, and recovery of soil carbon is even slower. Models are required for multi-temporal predictions of soil carbon changes, but these are only as robust as the data on which they are based.
- Understanding of the causes of observed changes in ecosystems is essential for sound policy development.
- An LTER network could serve as a catalyst to bring together scientists, resource managers and policy agencies, who will need to be informed of existing and proposed networks and systems for resource management currently under development. Future research programmes could then be better tailored to meet both local, regional, and national needs.
- An LTER network, while serving as a tool to better understand systems, should be further networked with other monitoring activities. This is essential to maintain the relevance of research at each site, while also meeting as many overlapping needs as possible, e.g., relating to environmental indicators programme, resource accounting and biodiversity monitoring.

Remote sensing and modeling

It is not suggested that remote sensing could replace the need for plot-based monitoring. Current technology is not sufficiently advanced, but with further development it could act as a method for verification and validation of the CMS. Verification and validation of a particular carbon estimation methodology is important in an international context since each country's efforts form only one piece of the requirements for the obligations under the Framework Convention on Climate Change.

Rather than duplicate the existing CMS in another country, or another country's CMS within New Zealand, a commonly proposed strategy is to use a surrogate carbon estimation methodology on a selection of sites in several countries using remote sensing and modeling to derive the carbon figures.

There are three major remote sensing technologies that can be used as estimators for above-ground biomass, Light Detection and Ranging (LIDAR), Optical Remote Sensing and Radar Remote Sensing (SAR). The principle advantage of all these methods, when used in conjunction with a space-based platform, is that they provide a globally consistent biomass estimator, provided the models used properly consider all the relevant factors in the environment.

As more capable remote sensing instruments become available, it is expected that more complex models describing biomass could be developed, resulting in improvements in the accuracy of biomass estimation. Also, gradual improvements in our understanding of the complex interaction between solar, laser or SAR illumination and the vegetation layer, will, in themselves, lead to models that more comprehensively describe vegetation from remote sensing data. For these reasons, no one remote sensing technology can be seen to have a clear advantage as the "perfect" estimator of biomass, for as one instrument is launched with a better capability, advances are inevitably being carried out on another. The best strategy would appear to be aware of the various technologies available from the literature, to note their strengths and weaknesses, and to be prepared, if necessary, to select the best features from one or more of these technologies.

Physiological process-based models

The use of process-based models, incorporating appropriate scaling procedures, provides a robust approach to estimating productivity by integrating across different scales ranging from leaves to stands. Such an approach is useful for estimating the effects of long-term perturbations to an ecosystem, such as the addition of nutrients or changing climate on the components of carbon balance and productivity. Outputs from the models can then be tested against long-term measurements of the change in carbon storage.

Progress to improve the capability of robust models to simulate changes in carbon storage at the ecosystem scale requires a rigorous approach based on physiological principles to investigate the processes of carbon input and loss at a range of scales from leaves to stands.

Research priorities to achieve this are:

- measurement of physiological properties for indigenous forest species and their distribution through canopies to model net carbon uptake
- determination of radiation-use efficiencies for forests with different water and nitrogen availabilities for use in modeling long-term productivity
- measurement of allometric relationships for tree components to determine ratios for allocation of carbon in relation to water and nutrient availability
- estimation of net carbon exchange for ecosystems, respiration from the soil surface and net carbon exchange for tree components to validate models; linking above- and below-ground processes of carbon uptake, loss and turnover in models.

Information system requirements (Dunningham & Gibb 2001)

The final work on the Information System for the CMS involved the compilation of information on a CD.

Included in the CD were :

- a copy of each CMS dataset provided as ArcView shape files
- A set of ArcView v3.2 projects containing maps of CMS data that can be browsed or colour printed
- A set of ArcView projects designed for using with CMS data
- A set of reports generated from the CMS data, which provide information required for reporting to IPCC and TBFRA 2000. They include:

Table 2 Reports from CMS Database

Reports	Description	Report File
National: Carbon by Vegetation Type (VCM)	Area and C Biomass table for each vegetation type and grouping	vcm1990.rpt & .rtf
National: Areas by Land Cover (LCDB1)	Areas for each LCDB land cover type	lcdb1990.rpt & .rtf
National: Carbon by Soil Climate Cell	Areas and Carbon in 0–10 cm and 0–30 cm for each soil-climate cell and vegetation type	soil_clim_luse.rpt & .rtf
Transect: Carbon by Plot summarised by land cover as mapped in LCDB1	Carbon in Live trees, shrubs and CWD for each Plot by LCDB land cover	tx_plot_lcdbc.rpt & .rtf
Transect: Carbon by Plot summarised by observed land cover at the plot	Carbon in Live trees, shrubs and CWD for each Plot by observed land cover	tx_plot_obsc.rpt & .rtf

10 Application of the Generalised Linear Model to Soils Data (Giltrap et al. 2001)

10.1 Introduction

The Generalised Linear Model (GLM) analysis was first applied to the soils data in mid-2000 and was re-applied in 2001 after

- revising the database to exclude sites that had not been in their current land use for long enough to approximate equilibrium and to replace close geographic clusters of sites with single composite points where appropriate
- using a digital elevation model (DEM) interpolated from 20 m contours to measure the nationwide distribution of slope, aspect and other topoclimatic variables and to compare this with their distribution in the database sites.

The analyses were extended by

- including the five depth ranges 0–10 cm, 10–30 cm, 0–30 cm, 30–100 cm and 0–100 cm rather than just 0–10 cm and 0–30cm;
- using categories derived from the LCDB as an alternative to the land-use classes derived from the Vegetation Cover Map (VCM);
- deriving estimates of the total national soil C inventory (at each of the five depth ranges) from the GLM analyses
- inspecting the individual model predictions for Soil-Climate/Land-Use cells and comparing them with the actual cell averages for the 30–100 cm depths (the Soil-Climate by land-use interaction was not significant for soil C at shallower depths than 30 cm).

10.2 Results of the analysis

- The database revision led to a substantial reduction in the number of exotic forest sites. This was partly due to the exclusion of recently planted forests but mainly to the amalgamation of clustered sites into composites. There was a much smaller reduction in the number of sites in other land-use categories and a substantial increase in the number of arable sites as a result of reclassification of the land use on sites in pasture/arable rotations.
- A simple additive model using soil-climate category, land-use (or LCDB) category and the product of annual rainfall and slope gave the best prediction of 0–10 cm, 10–30 cm and 0–30 cm soil C. This model means that a single "land-use effect" can be applied across all soil-climate categories.

- the model for these depths worked equally well for LCDB or land-use categories and was not particularly sensitive to the inclusion or exclusion of predictor variables other than soil-climate and land-use (or LCDB).
- The 0–30 cm land-use (or LCDB) effects show only negligible differences between pasture (grassland) categories, substantial reductions (-30 to -50 t/ha) for the forest categories and intermediate reductions (-14–20 t/ha) for arable, horticulture and scrub. These values are not materially different to those given in Report XII.
- The corresponding land-use (or LCDB) effects for 0–10 cm soil C show a material reduction in the effect for exotic forestry (-5 t/ha) compared with that in Report XII (-21 t/ha). This is probably because of the exclusion of "young" or otherwise unsuitable sites. The results for other land uses are comparable to those in report XII.
- The analyses for 30–100 cm (0–100 cm) soil C was unstable and dominated by the influence of very high "inert" organic matter at depth in podzols. It may be possible to produce a stable model if podzols are excluded, but this will also exclude most existing indigenous forest sites. The soil-climate by land-use interaction term was significant for the 30–100 cm and 0–100 cm depths but not for 0–10 cm, 10–30 cm or 0–30 cm.
- The estimates of the national soil inventory from the GLM are 1131 Mt (0–10 cm), 1296 Mt (10–30 cm) and 1304 Mt (30–100 cm). Compared with earlier estimates, this shows close agreement for the 0–10 cm, a modest (8%) reduction for 10–30 cm and a substantial (20%) reduction for 0–100 cm. The reduction for the 0–30 cm soil C was due partly to the database revisions and partly to the way soil C was estimated for unsampled cells. Using the additive model instead of individual cell averages for sampled cells did not contribute to the observed reduction.

11 Influence of Land Use History on Coefficients of Change

Of the 455 sites in the database, 37% recorded no history of land-use change, 9% recorded a change, and 54% recorded no data about land-use change. Because the Landcare Research National Soils Database sites were normally placed on undisturbed and stable sites, it is assumed that for the 54% of sites with no land-use history data, no change in land use in the 10 years before sampling has occurred. Of the 9% of sites that recorded a change in land use within 10 years of sampling, 19 sites were identified to be removed from the database and 20sites were recommended for reclassification of their land use. Soil C estimates made before and after deletion or reclassification of these sites showed no difference.

12 Potential Other End-User Requirements

12.1 Background

The information required for a carbon monitoring system that meets the standards required of the Framework Convention on Climate Change (FCCC) also provides many of the elements required for other monitoring and reporting purposes. In particular there is likely overlap with biodiversity monitoring needs of DOC and MfE and the wider monitoring needs of the Environmental Performance Indicators Programme (EPIP), also managed by MfE. There are also other requirements for Regional Councils and Territorial Authorities and MAF.

The various synergies with other proposed monitoring systems are summarised below.

12.2 Other MfE programmes

- Soil has been a component of both the development of the CMS and the EPIP and is considered to be a strong unifying link
- The CMS is concerned with soil carbon levels and how these change with land use. The EPIP is focussing on core indicators for land/soil-intactness pressures and degree of erosion/soil-health pressures and indicators (where one of the Stage 1 EPIP indicators is percent carbon)
- Land-use pressures are determined by considering the match of land cover (LCDB) and land capability/soil type. The approach to determine this is the same for both CMS and EPIP
- Carbon will always be used for both the CMS and the EPIP land theme
- MfE EPIP and DOC share the interest in monitoring forest biodiversity, a feature of the indigenous forest and scrub monitoring system, and this critical soil characteristic will need to be monitored.

12.3 With MAF

- Sustainable land management
- Reporting to OECD (Agriculture, Food and Forestry Directorate)
- Reporting to FAO Forestry Department (TBFRA2000)
- Indicators of sustainable forest management (Montreal Process).

12.4 With DOC

- Convention on Biodiversity
- Indigenous Forest Condition supplementing DOC’s network for private land
- Convention of wetlands of international importance.

12.5 For local government and others

- Assist Regional Councils in State of the Environment Reporting
- Contribute to the research programmes of a variety of science providers.

13 Integration of the LCDB with the CMS (Stephens et al. 2001)

The LCDB1 has been used to establish a 1996 baseline estimate of carbon in soils, in indigenous forest and in scrub. Error estimates associated with mapping the aerial extent of indigenous forest and scrub as well as carbon calculation have been determined. A map depicting the distribution of national soil carbon and carbon in indigenous forest and scrub has been produced. The total carbon stored in indigenous forest and scrub for 1996 was estimated at the 95% confidence level to be 1149 (± 50) x 10^6 tonnes 153 (± 80) x 10^6 tonnes, respectively. A high error was found to be associated with the estimation of carbon in scrub because a limited number of plots were used for the calculation.

It is expected that a second LCDB will be established over the next 18 months. Since this second database (2001/02 LCDB2) would be backward compatible (with respect to the land cover classes mapped previously) with the first (1996) LCDB, it is important that the carbon monitoring system uses the LCDB1 and not the VCM as the source of land cover information for accounting purposes. Several key issues associated with using the LCDB for operation carbon monitoring have been addressed, including: the number of scrub plots; mapping arable cultivation; a land-use activity that affects soil carbon; the over-mapping of bare ground; and the generalised LCDB vegetation classes.

For national carbon accounting purposes, a verifiable 1990 baseline will be required. Such a baseline could be derived from the 1996 LCDB. A recommended method would use sampling of aerial photography and satellite imagery to quantify land-cover change between 1990 and 1996, and would combine these changes with the LCDB to get a 1990 estimation of land cover. The 1990 land cover would then be combined with the GLM model of soil carbon and an equivalent regression model of indigenous forest and scrub carbon to produce a 1990-carbon budget. As the transition of scrub to indigenous forest is too subtle for detection by remote sensing, a simple growth model and scrub age distribution will also be required. Special attention will have to be given to using a confusion matrix of the LCDB to counteract random and systematic errors of the LCDB.

14 Improved Allometric Functions for Forest and Scrubland (Beets et al. 2001)

There is a lack of biomass data for New Zealand indigenous species and for scrub but progress was made in the final year of the programme in extending the amount of biomass data for indigenous forest and scrub through historical data and new measurements. The measurements were carried out according to strict protocols developed for the CMS. An associated methodology for calculating coarse woody debris was also developed.

15 Forest Sampling Options for the CMS

A short report covering concerns raised in the international review of the CMS recommended that:

- Tests should be made of how the grid could be resolved into smaller or larger grid sizes including the use of nested plots
- The pros and cons of selecting plots within a grid cell in a randomised manner be investigated
- A method for estimating C stocks and their changes at varying levels of desired precision in different LC/LU classes and the implications for costs be addressed.

16 Costs of a Proposed Structure

These costs are preliminary and reflect the views of the lead author of this task from Forest Research prior to the completion of the operations manuals.

16.1 Costs variations

The costs of the CMS will depend on:

- the mandate of the CMS
- the organisational structure employed and
- the number of sample plots to be measured each year.

The following costs assume a 9 km grid sample scheme with the LCDB carried out every 5 years; first plot remeasurement interval of 5 years; and a long-term plot remeasurement of 10 years.

Costs are incurred under the following broad categories:

Staff
Field measurements and Quality control
- Forest and shrub
- Soils
Information technology and administration
Laboratory work and function coefficient estimation
Operational Research and Development (Non FRST)

16.2 Staff

Management (half time spent on duties other than operational CMS):
- Technical manager
- Operational supervisor.

Field measurement, 3 to 4 field crews employed on the CMS during the summer only:
- 3–4 permanent staff, field crew leaders
- 9–12 temporary field workers.

Database administrator (10%).
R&D and IT development, on contract as required.

Technical manager

Duties consist of managing the unit, external liaison, managing the technical components of the CMS system, coordinating ongoing development and research, ensuring standards are met, and analysing, reporting and promulgating results. Tertiary, preferably post-graduate, qualifications.

Annual salary $65,000 x 2.35 overheads multiplier

Operational supervisor / executive officer.

Duties consist of managing the field programme, recruiting temporary staff, managing training, supervising quality control procedures, analysing data. Tertiary qualifications. Annual salary $57,000 x 2.35 overheads multiplier, 135,000/year, half-time 65,000

3–4 permanent field technicians (crew leaders)

Permanent staff are responsible for leading a field crew and ensuring temporary crew members operate to the desired standards. They work on the CMS only over the summer measurement season. Note that the 50% loading of the operational work time for "down time" permits these staff to carry out other duties besides field measurements with a higher level of responsibility than the temporary staff. An annual salary of $ 40,000 to 45,000. Tertiary, technical qualifications.

9–12 field workers

Recruited each year, preferably returning over several years. Ideally, these should be tertiary educated, perhaps studying for post-graduate degrees in fields related to indigenous forest/shrub ecology. Major attributes are knowledge of NZ native flora (species recognition), physical fitness, a love of the outdoors, bush and tramping skills, accurate and careful measurement techniques.

All field technician costs are accounted for in the field measurement cost expressed on a plot measurement basis, below.

Data processing/Database administrator

Annual salary $30,000 to $ 35,000, but only 10% of a year (i.e. 4 to 5 full-time equivalent weeks) would be devoted to the CMS work. A permanent position, probably shared to allow backup, ideally carrying out these duties and administering one or more other similar databases. Duties include assisting in preparing data before a field crew's work, (e.g., downloading previous measurements of a plot to a field computer or to field sheets), processing data from the field, database error corrections, retrieval of data on request, preparation of data for analysis.

16.3 Direct costs per measured forest and shrub plot.

The field procedures have been designed so that one field crew of two to four staff could measure one plot in 1 day, on average, for those days spent measuring, excluding necessary "down time".

The costs of the forest plots and shrub plots are identical, as the work for either occupies a full day. The time saved on a shrub plot by not having to measure many tree stem diameters and heights is balanced by the additional work in collecting biomass samples. Similarly, the additional cost spent in establishing a new plot, laying out internal and external boundaries, and tagging stems, is balanced by time spent looking for and then refurbishing an existing plot.

The 62 plots in the South Island Transect exercise were measured by a field crew over a 3-month period in the summer of 1998/99, during the university vacation.

The crew managed 0.94 plots per weekday, on average, including time lost due to bad weather and to logistic requirements, but the season included a total of 11 days working at the weekend. A further 3 days were spent by the permanent staff in measuring 3 plots after the departure of the university students. As there was exceptionally good weather during that particular summer and only 7 days were lost due to inclement conditions, it is recommended that additional time, about 14 days, should be allowed for bad weather in a typical year. Also, because the transect was close to Christchurch and the major highway of Arthur's Pass, the 7 days spent in preparation and road-travel relocating from one base to another (logistics) should also be doubled, under typical conditions, to 14. A further 5 days is required at the start of the season for training when no plots are measured. This excludes training days where plots are measured.

In summary, to measure 62 plots in one season by one field crew would normally require

58 days spent measuring,
5 days training (non productive)
14 days relocation and preparation
14 days lost to inclement conditions.

TOTAL 91 days

AVERAGE 1.5 field crew days per plot

A field crew consists of 4 people, comprising:
1 field crew leader, experienced, permanent staff, ($43,000 / yr) $170 per day
3 field workers, temporary, ($13.75 /hr, 28,600 / yr), each person$110 per day

Direct cost of field crew wages (3 @ 110 + 170)	$ 500 per day
Assume an indirect overheads multiplier of 2.35,	
cost of field crew, excluding direct operating costs	$1175 per day
Operating costs per day (average, from the SI transect exercise)	
(Vehicle, Helicopter, accommodation, daily allowances, equipment and gear)	$ 325 per day
TOTAL cost per day	$1500
TOTAL cost per plot	$2250

During a day spent measuring a plot, about half the time is used on accurately locating the plot and getting to it. Access, even over short distances, can be extremely difficult and time consuming. The time could be reduced by increasing helicopter use, but only at considerably more expense along with an increase in the risk of delays due to unsuitable weather for flying. About one-third of the time is spent at the plot on work and measurements necessary to estimate the amount of carbon per hectare. Additional work, not strictly necessary for a carbon monitoring system but that provides essential and useful information for other stakeholders, takes about one-fifth of the time of a forest plot and less than one-tenth of the time of a shrub plot.

	% of time	
Task	Forest plots	Shrub plots
Locating plots	50	49
Measurements for carbon	30	28
Destructive sampling for carbon composition	-	13
"Extra" measurements	20	9

In total, non-core CMS work takes only about one-sixth of the field-work time. Given the integral nature of one plot in 1 working day, restricting the nature of the work to a carbon monitoring system alone would have marginal savings overall.

16.4 Soils monitoring costs – options

The principal ongoing costs of the soil CMS will be in strengthening the robustness of the system by ongoing soil sampling and analysis for:

1. Soil carbon stocks per hectare, especially for those land uses for which only limited data are currently available (e.g., indigenous forest, scrub)
2. Change in soil carbon over time as a consequence of land-use change.

Soil carbon stocks

To strengthen the existing soils data base, five climate/soils/land-cover cells need to be sampled at six sites each. Within a plot, four sites chosen objectively will be measured for bulk density, litter and percentage carbon composition. Soil sampling down to 1 m is estimated to require two people for 1 day, plus a further 33% contingency or "down time", resulting in a cost of $2100 per site, including labour, transport and accommodation costs, but excluding laboratory sample preparation and analysis. This work would be spread over 5 years.

Total cost over the first 5 years: $12,500 per year.

It is proposed that sampling for soil carbon, at least to a depth of 0.3 m, be carried out with the routine 20 x 20 m vegetation plot measurements in the indigenous forest and soils. The number of within-plot sites for soil sampling will be maintained to ensure the standard day's work is not exceeded. The costs for these are calculated above in the forest and shrub field operations.

Change in soil carbon over time

Repeated sampling over time will be carried out at permanently located sites paired to represent the key land-use changes of pasture to pine and pasture to shrub-land. Process-based models will increasingly be used to indicate the trajectories of these soil carbon changes over an appropriate time scale (e.g., 20 years), from which more accurate annual changes can be inferred. These model predictions will need to be confirmed for key land-use changes by remeasuring soil C using the benchmark research sites, where soil carbon measurements were made at the time of the land-use change. Over the first 8 years of the CMS, 32 pairs of sites would be established over the first 8 years of the CMS, taking 10 days work at a cost of $23,000 per pair. Some sites would have to be abandoned through disturbance, resulting in additional cost of replacement, bringing the cost to $110,000 per year. A further $16,000 per year is required for reporting.

Total cost over the first five years: $126,000 per year.

16.5 IT development and support / on contract

Develop and maintain the operational data base, analysis and reporting system, integrated with a CMS GIS, that contains a copy of the LCDB. The costing assumes a new version of the system is developed every 10 years, requiring 2 to 3 FTE years (2.5 FTE). This development could cost $400,000 including interest, with costs spread over the 10-year period. However, most of the costs would be incurred within the first few years. The annual allowance of $50,000 would cover amortisation costs, system maintenance and database administrator costs, but exclude extraordinary costs incurred by web-based analysis and results system.

16.6 Laboratory analysis and estimation of function coefficients

Laboratory analysis costs are an essential part of the CMS, both for the forest and soils components, to determine carbon content of samples. The development of better allometric functions to predict above-ground biomass is an ongoing requirement to remove systematic errors in the system. These services can be contracted.

16.7 Operational research and development

Costs will increase over those incurred strictly to meet an operational role if operational research into improving measurement, sampling and analysis techniques is to be funded within the CMS. This R&D can be carried out as part of the permanent staff's duties, or it can be contracted out. It would quite properly be additional to any PGSF funding from FRST, as it is specifically aimed at improving the efficiency of the CMS, a central government initiative. An allowance of $100,000 per year is sufficient for less than one full-time equivalent, and is the worthwhile minimum amount. Scandinavia and the USA have shown that the investment in operational R&D in this area is well targeted.

16.8 Summary of costs "Base Case" for a 9 km grid

In the first 5 years of operation, the total number of plots to be established is expected to be 1075, or 215 per year. A further 21 to 22 of the plots should be remeasured within the same season for quality control. In years 6 to 10, these plots are to be remeasured, so that by 2012, an estimate of the change in forest and shrub composition and carbon stocks can be obtained. The annual direct field measurement cost at $2250 per plot totals $480,000, with a further $50,000 allowed for QC.

Technical manager (half time)	75,000
Operational supervisor (half time)	65,000
Field measurements–forest and shrub plots	480,000
Quality control and assurance	50,000
Soils	138,000
Database administration, IT development annualised	50,000
Laboratory costs	10,000
Estimation of coefficients, allometric functions for trees, larger shrubs	50,000
Operational R&D	100,000
CMS subtotal	1,018,000
Land Cover Data Base annualised	600,000

TOTAL per year $1,618,000

16.9 Cost variations

An alternative model is to locate the unit in a department where it is necessary to employ the technical manager and operational supervisor full time on the CMS, with correspondingly less chances of allocating alternative work to the permanent field-crew leaders. This would increase costs by $ 140,000 to $200,00 per year over those stipulated above. The cost for the CMS sub-total would rise to between $1,176,000 and $1,236,000 per year.
Savings could be achieved through substantially reducing the amount of work in the soils monitoring system by deferring research into the nature of change of soil carbon composition as land-cover changes, which is carried out using 64 long-term paired and benchmark sites at a cost of $126,000. Operational R&D at $100,000 could also be curtailed, with combined savings of $226,000.

The development of the IT systems could be postponed until after the second financial year, but postponement much beyond that time would greatly increase the risk of data loss or corruption. It is also possible to extend the first round of measurements from 5 to 10 years, saving a further $270,000 (including corresponding reductions in QC and laboratory costs). Thus the cost for the CMS subtotal could be as low as $480,000 for the first and second years of operation.

A less risky cost reduction would be to envisage the first year as a start-up operation, but measuring the full complement of plots on the 5-year cycle, with a cost of $720,000 for the year. In the second year, a commitment would be made to the IT database development, with a less severe reduction in the soils monitoring and operational research programmes.

Note that the IT development would incur a cost of $350,000 to 400,000 perhaps spread over 2 financial years. There would be no need to incur costs of this magnitude for a further 8 years or so. Similarly, once all plots had received one remeasurement, after 10 years the remeasurement interval could increase to 10 years, thus halving the annual field costs. Alternatively, the field costs could remain the same but more plots could be established at new sample points.

The costs discussed so far are significantly less than those incurred by other countries. It is predicted that as the usefulness and value of the data are appreciated, and international agreements become more demanding, the intensity of sampling will increase not diminish. This will almost certainly result in more plots being established, either by establishing plots in specific regions or areas of high interest using a supplementary grid or sampling scheme, or by adding a second grid across the whole country. Decreasing the grid size at the outset would solve many problems. A grid of 5 km square would be similar to the density of plot clusters employed in the new USA FIA. The number of forest and shrub plots would be expected to increase to about 3560. Not all costs would rise proportionally, and it is estimated that such an intensity of measurement could be achieved for a CMS costing perhaps $2.25 million per year, plus the annualised LCDB cost.

17 A Proposed Structure for the CMS

17.1 Science provider suggestions

A small group of professionals could maintain the CMS, overseen by a manager reporting to a Steering Committee. Other national environmental monitoring requirements could be managed under the same umbrella to ensure the most efficient use of resources. Contracted staff, including students and recently qualified scientists, would be part of the field staff employed as required for field work. Training a new generation of scientists to be involved in the monitoring system would be one requirement of the management of the CMS.

The CMS structure would be charged with:

- defining the overall work programme
- organising the field work including the sub-contracted staff
- managing data storage and analysis
- preparing reports and liaising with public and stakeholders.

17.2 Steering committee proposal

The Steering Committee in July 2001 sought a joint Year 1 implementation proposal from the two CRIs that had developed it thus far. In this request the Steering Committee stated that: "The funding profile for the CMS work is constrained in 2001/02 but improves in the following two years. The funding is sufficient to begin the CMS fieldwork, data collection, data entry, archiving field records and some analysis. Funding has also been obtained for the next New Zealand Land Cover Database project (NZLCDB#2), an essential adjunct to the CMS. This will commence with image acquisition over the coming 2001/02 summer months."

The CMS Steering Committee defined their proposal for year 1 of the CMS implementation as follows:

- It should contain an implementation plan on how the work described in the manuals (as prepared under Task A3 of the 2000/01 work plan) can proceed in Year 1 with a target 'start date' for the fieldwork to begin in the week following Labour Day 2001;

- It contains details on how the field work in Year 1 can be staffed and controlled in accordance with all relevant labour legislation, safety, health and land owners/managers access requirements. This is also to contain details on training for the teams;

- It describes how the data collected in Year 1 are to be securely stored and 'future-proofed,

- It describes how the soils data obtained during the Year 1 fieldwork programme are to be processed, stored and analysed;

- It describes how the vegetation data and specimens obtained during the Year 1 fieldwork programme are to processed, stored and analysed;

- It required a fully costed proposal for carrying out the above, showing salary costs, the different operating costs, and overheads. Staff costs must be appropriate to the skill levels for the tasks and should make the contractual status of any employees quite clear. The future scientific and other benefits Landcare Research and Forest Research from satisfactorily implementing the data collection and initial analysis component in the Year 1 proposal should be factored into the costings. Any subsidisation from related work already funded by the taxpayer should be identified and shown explicitly. Normal CRI charging overheads will need to be discounted to achieve the Year 1 funding constraints.

Further operational research work is to be considered separately for funding.

The development of a new database to hold, analyse and report the CMS data (database analysis requirements and database networking options) will be separately considered for funding in 2002/03.

In preparing the implementation plan, the following assumptions are to be made:

- the grid size will be 8 km (this is expected to require 1400 permanent field plots of which 280 are to be established in Year 1);

- the grid will cover the whole of New Zealand's sovereign land territory except for the Ross Dependency (in general this means the North and South Islands, Stewart Island, the Chatham Islands, and other off-shore islands such as the Auckland Islands, the Kermadecs, etc.);

- the entire grid will be actioned over a 5-year period in the first survey round (Round 1). Subsequent to this it may be actioned over a 10-year period;

- field work in 2001/02 will be restricted to the North and South Islands and minor off-shore islands coming within the territorial authorities' boundaries. Stewart Island and the Chatham Islands and the other remote off-shore islands will be specifically excluded from field work in 2001/02;

- for cost and operational efficiencies some clustering of the permanent plots to be surveyed in 2001/02 is desirable. This should take into account that several parts of the North and South Islands are poorly represented in the NVS databank (in terms of previously established permanent plots) and that there should be some balance between establishing new plots and using previously established plots within NVS which meet the inclusion criteria in terms of the national 8 km grid;

- formal permission from land owners/managers or their agents will be required before entering any land for the field work. This will include compliance with any protocols they may wish to apply, including any required under relevant legislation. In the event of permission being denied, the intended plot at the grid point will not be established in Year 1;

- a copy of all data obtained from any fieldwork on their property is to be available on request by the land owners/managers or their agents;

- ownership of all data collected during Year 1 of the CMS will be vested with MfE, on behalf of the Crown. MfE will normally place it within the public domain after a reasonable period of time and with the consent of the land owners/managers or their agents;

- the field work season will be from the week following Labour Day 2001 (Labour Day 2001 is Monday 22 October 2001) and is expected to continue, in normal circumstances, until Easter of 2002 (Good Friday 2002 is 29 March 2002). This is a field week season of approximately 21 weeks with allowances made for the Christmas–New Year break. Subject to progress and favourable weather it may continue beyond this to 30 April 2002;

- capacity for up to 12 permanent staff from the CMS Steering Committee parent departments (DOC, MAF and MfE) should be factored into the planning. These staff may be available to be trained and be used for some periods of time in the field work teams from 1 February 2002 until the close of the 2001/2002 field work season. Discussions within the parent departments are required before this commitment can confirmed;

- soil sampling in the forest and scrublands plots will be carried out concurrently with the vegetation measurements;

- soil sampling will be to at least a depth of 0.3 metres at each forest and scrublands plot;

- four (4) paired sites for the repeated sampling through time of soil carbon changes are to be established in the first year and are to be located, where they meet the soils stratification schema, on the national 8 km grid system;

- ten percent (10%) of the indigenous forest and scrublands permanent plots are to be revisited during the Year 1 field work season for quality control and quality assurance purposes. The results of these revisits are to be detailed in the audit material made available to the Steering Committee.

18 Concluding Remarks

The 5-year development of the CMS has resulted in a working system that is ready for implementation. The design of both the forest/scrub and soils components have been tested locally and reviewed internationally. Links have been made with other national initiatives that, if developed, could provide considerable operating efficiencies.

Operating manuals will be completed in time for the first field season in early 2002. Data management, processing and reporting requirements remain to be decided.

The CMS is based on land and vegetation information, gathered many years ago, that provided a solid foundation. It demonstrates the value of the collection of basic land information and long-term monitoring to understand the impact of anthropogenic activities. A vision of many researchers and practitioners of environmental management is to have a cost-effective, comprehensive, up-to-date land information system as a national resource. The CMS could provide the nucleus of such a system.

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20 APPENDICES

20.1 Overview of the development of the CMS and the system applied to exotic vegetation

Element	**Managed/exotic vegetation**	**Indigenous vegetation**		**Soils**
	Forest	Forest	Scrub	
Environmental and spatial data requirements:				
Current Land cover/use	LCDB	LCDB (1995–6), NVS		VCM (1981–5); NZLRI
Climate				Climate surfaces
Soil				NSD (IPCC mod.)
Classes	Planted forest	Indigenous vegetation		Soil/clim by LU cells
Data collection	Survey based • Grower survey (age, area, regime) • PSP (regime yield by region) • Harvest • above/below ground biomass and litter/slash	Plot network • grid (e.g., 8x8 km = 500 forest) NVS • post-stratified • above/below ground biomass • CWD (>0.1 m dia.) • other data (pests, species, condition etc.)		Plot (baseline) • pre-stratified • 6 representative plots per cell minimum • organic soil carbon at 3 depths • litter (<0.1 m dia.) • other data (N, P?)

Method of carbon estimation	Estate age class and yield modelled with allometric equations based on extensive dataset	Plot C estimated and scaled by class extent, allometric relationships for biomass based on single dataset	Baseline constructed by sampling limited plot C and scaling by cell extent
Results	C stock and annual change in C with (assessed) high level of accuracy	C stock with known accuracy (number of plots for level of accuracy known)	C stock with (assessed?) accuracy (number of plots for given level of accuracy unknown)
Future change in carbon detection	Repeat survey and model estate (annual)	Repeat LCDB and resample plots (5–10? year cycle)	Repeat “hybrid” LCDB (+?) and 2° spatial data sources (if possible) to update LU extent and model change based on COCs (10–20? year cycle)
Reporting			
FCCC reporting	Yes	Yes	Yes
Kyoto Protocol	Yes	For regenerating scrub	?

20.2 Summary of CMS Development Reports

MfE Carbon Project Reports 1996/97

1 Daly, B.K.; Wilde, R.H.: Reclassification of New Zealand soil series to IPCC categories. MfE Contract Report LC9697/096.
2 Leathwick, J.R.; Giltrap, D.J.: Climate Information. MfE Contract Report JNT9798/002.
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4 Landcare Research & Forest Research Staff: Determining an appropriate carbon monitoring system for New Zealand's indigenous forest and scrub. MfE Contract Report JNT9798/010.
5 Gibb, R.G.; Campbell, S.P.; Pilaar, C.; Dunningham, A.: Information system for carbon monitoring in indigenous forests, scrub and soils. MfE Contract Report JNT9798/011.
6 Gibb, R.G.; Campbell, S.P.; Pilaar, C.; Dunningham, A.: User requirements and user requirements determinations with supporting documentation. MfE Contract Report JNT9798/012.
7 Dunningham, A.; Newsome, P.F.J.: Progress report to the Steering Committee on "Estimating the extent of indigenous forest and scrub". MfE Contract Report JNT9798/023.
8 check order of authors Allen, R.; Beets, P.; Bellingham, P.; Hall, G.; Kimberley, M.; Wiser, S.: Catalogue and evaluation of existing data sets for forest classes and scrub in New Zealand. MfE Contract Report JNT9798/024.
9 1996/1997 Report to MfE from the Information Systems Project Team: Progress report to the Steering Committee on "Estimating the extent of indigenous forest and scrub"
10 Newsome, P.F.J.; Willoughby, E.J.: Land Use/Land Cover Information. MfE Contract Report JNT9697/103.

MfE Carbon Project Outputs for 1997/1998

11 Tate, K.R.; Giltrap, D.J.; Daly, B.K.; Wilde, R.H.; Scott, N.A.; Willoughby, E.J.: Revision of data layers and overlays. MfE Contract Report JNT9798/085.
12 Proposed sampling system and national network of permanent plots for a NZ carbon monitoring system (including the 1990 baseline)
13 McNeill, S.; Scott, N.; Pairman, D.; Belliss, S.; Beamish-White, R. Measuring forest biomass using multi-polarisation, multi-wavelength radar imagery in New Zealand: A first assessment. MfE Contract Report JNT9798/088.
14 Completed set of coloured national maps of forest classes
15 Report on the methodologies and results of Task 1 (i.e. to complete a national coverage of forest class boundaries)

16 Wiser, S.; Allen, R.; Beets, P.; Kimberley, M.; Herbert, J.: Progress report on the national functions for carbon accounting purposes, forest and scrub in New Zealand. MfE Contract Report JNT9798/152

17 Report covering points in Task 2 (i.e. the IPCC agreement)

18 Gibb, R.G.; Dunningham, A.; Campbell, S.P.; Pilaar, C.: Specification for meta-data elements and meta-data entry system for MfE carbon program. MfE Contract Report JNT9798/098.

19 Newsome, P.F.J.; Beets, P.; Page, M.J.; Bellingham, P.; Dunningham A.; Allen, R.: Estimating the extent of scrub and indigenous forests. MfE Contract Report LC9798/140.

20 Gibb, R.; Campbell, S.; Dunningham, A.; Pilaar, C.: Implementation specifications for carbon monitoring information system for indigenous forests, scrub, and soils. 1997–98 report to the Ministry for the Environment. MfE Contract Report JNT9798/136.

21 Final aerial extent and spatial location estimates of forest and scrub areas by vegetation class, to depict the 1990 situation

22 Tate, K.R.; Daly, R.H.; Wilde, R.H.; Nordmeyer, A.; Oliver, G.; Scott, N.A.; Smith, C.T.; Giltrap, D.J.: Updated 1990 soil carbon baseline. MfE Contract Report JNT9798/133.

23 Scott, N.A.; Giltrap, D.J.; Tate, K.R.; Smith, C.T.: Initial estimates of land-use effects on soil carbon: Estimating coefficients of change. MfE Contract Report JNT9798/148.

24 Hall, G.; Wiser, S.; Allen, R.; Moore, T.; Beets, P.; Goulding, C.: Estimate of the carbon stored in New Zealand's indigenous forest and scrub vegetation for 1990. MfE Contract Report JNT9798/147.

25 Allen, R.; Wiser, S.; Hall, G.; Moore, T.; Goulding, C.; Beets, P.; Nordmeyer, A.: A national system for monitoring change in carbon storage in indigenous forests and scrub: testing plot locations on South Island transect. MfE Contract Report JNT9798/166.

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30 Lawton, M.E.; Stephens, P.; McFarlane, P: Monitoring carbon in soils, indigenous forests and scrublands: 1997/98 summary report. MfE Contract Report JNT9798/162.

MfE Carbon Project Reports 1998/99

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32 Davis, M.R.; Wilde, R.H.; Oliver, G.; Scott, N.A.; Tate, K.R.; Giltrap, D.J.; Betts, H.; Chinnery, P.; Nordmeyer, A.: Updated 1990 soil carbon baseline. MfE Contract Report JNT9899/146

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