


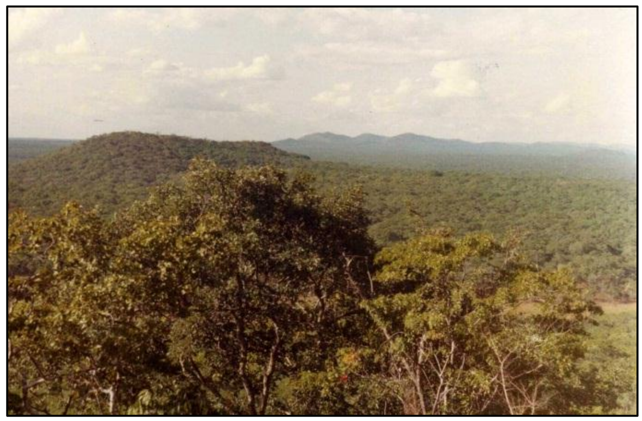

Securing Land Resources: Information Needs Today and Tomorrow

State-of-the-Art Review

David Dent and Barry Dalal-Clayton

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Securing Land Resources:
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PREFACE

Sustainable use and management of land resources depends on good intelligence about their location, their condition and how this condition is changing. During the years of plenty, the attention of governments was elsewhere and now, for all our information technology, information on natural resources is dispersed, fragmented, and used less and less. Perversely, when competing claims on natural resources are greater than ever, fundamental knowledge of the land is spurned.

In this review, we assess the current status of land resources information, what information is used in land use policy, planning and management, and what information is actually needed. It is not our aim to describe in detail the many tried-and-tested approaches to land use and development planning or the array of support and information tools; we have reviewed the most widely used in earlier publications (Dalal-Clayton & Dent 1993, 2001, Dalal-Clayton and others 2003). However, we discuss some innovative methods and information systems that have matured during the past decade, including applications of digital elevation models, predictive ecosystem mapping, satellite imagery, airborne geophysics and land resource information systems.

The picture is uneven. The information wanted for exploitation of mineral and energy resources, smash-and-grab raids on forests, and the terrain and climate information needed by the military, aviation and shipping is better than ever. What has been neglected is fundamental information on renewable resources: soils, water and ecosystems, farming and pastoral systems, and their social context. Once-great institutions like FAO, the overseas survey agencies of the former colonial powers, and commercial companies that undertook major projects in land resources survey and development have been cut back or dismembered.

There are also contrasts country-wise. Two giants, China and Brazil, have continued to improve their information and expertise; the Western World has privatised it; Eastern European countries in transition to market economies struggle to maintain capacity; and many poor countries that depended on technical assistance have given up. We need to dig more deeply into the link between knowledge of the land and the ability to make good decisions about land use and management or, even, to see when a decision is needed but, on the world stage, the information needed for food and water security, adaptation to climate change and resilience against natural hazards is simply not there. For most of the world, the data we have are more than thirty years old and the capacity to interpret them has been pensioned off.

We conclude with steps that should taken to put things right.

David Dent and Barry Dalal-Clayton
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CONTENTS

EXECUTIVE SUMMARY

'Are we to decide the importance of issues by asking how fashionable or glamorous they are, or by asking how seriously they affect how many?'

Nelson Mandela

A perfect storm

The land provides 95 per cent of our food and clothing, and all timber, bio-fuels and fresh water. Services provided by the soil - including nutrient cycling, control of pests and diseases, and regulation of climate and the water cycle - underpin every ecosystem. And they are taken for granted! Between 1965 and 1980, the *green revolution* increased crop yields almost three-fold; for a generation, food production was carried ahead of population growth and political attention turned away from land, food and agriculture. But the revolution has stalled and today's policy-makers face all the old challenges writ large - and new ones:

- ***Burgeoning demand*** means that, by 2050, 70 per cent more food will be needed than now – double in developing countries. This must come from the same land and water resources or, if present trends continue, much less; there are no great reserves to draw on.

- ***We have passed peak soil.*** The area under cereals peaked in 1981, grain production *per capita* peaked in 1987 and the total extent of arable land peaked in 1991 (Figure 3). As wealth has brought increasing demand for meat, more and more grain has been diverted to stock feed. More recently, significant areas are being turned over to the production of bio-fuel, and, every day, tracts of the best land are lost to cities and connecting infrastructure.

- ***Land and the environment are, increasingly, being degraded.*** On top of historical soil erosion, the last quarter century has witnessed degradation of one quarter of the land surface. Industrialised agriculture is driving soil degradation, water shortage and contamination, loss of biodiversity, and climate change.

- ***The food system is unsustainable***. The green revolution depended on cheap fuel, fertilizer and irrigation applied to new, responsive crop varieties. Fuel and fertilizer are no longer cheap; water resources are over-committed; and crop yields have levelled off - in the heartland of the green revolution, yields and response to inputs have been falling since the 1980s.

- ***Climate change is driven by burning fossil fuels and land use change***. It will bring more-severe droughts and more-intense rains; for instance, half of what is now India's high-potential wheatland is likely to be heat-stressed, short-growing-season cropland by 2050; and it appears inescapable that rising sea level will flood great cities and productive farmland.

A recent UK All-Party Parliamentary Inquiry into Global Food Security (APPG 2010) predicted collision between ever-growing demand for food, energy and fresh water, the stresses of climate change (and we would add land degradation), destabilisation of governments that cannot provide their people's basic needs, and increasing migration from poor countries to those better endowed. Yet, knowledge of the land and the institutional capacity to face up to the issues has atrophied. *'A perfect storm'* - and no charts!

The end of cheap food and fuel (Figure 1) has concentrated minds on food security. One response is the international land grab - where the power lies with the big players and which does nothing to help the global situation. A sustainable alternative combines conservation agriculture with precision farming but this is 'high farming' that demands high knowledge, much better land resources information, and re-learning much that has been forgotten.

Figure 1: The end of an era: world food prices 1990-2012 (FAO 2012)

Natural resources information

Land capability depends on interactions between climate, terrain, soils, vegetation and management. It's not all the same out there; timely, accurate information reduces risks - so policy-makers and planners need to draw on a broad spectrum of specialists and trans-disciplinary know-how. The hungry decades after the Second World War were a Golden Age of land resources surveys: in the years of plenty that followed, political attention turned elsewhere and land resources information is no longer the bedrock of development policy and planning - it is the policy makers' blind spot. For more than a generation, we have witnessed:

- *Disinvestment in land resources survey, monitoring and database management.* China and Brazil are telling exceptions.

- *Uncertain access to data.* Fundamental data are dispersed, fragmented and forgotten. Most databases were created in response to yesterday's issues. They are incomplete, data sets of related fields are not linked, and vital data are, sometimes, maintained in an amazingly amateur way without adequate funding or any credible strategy for continuation and development.

- *Erosion of specialist skills within natural resources agencies and universities* has created capacity gaps that will be hard to fill. Most of the land resources data we have are more than thirty years old. Without the capacity to interpret them, let alone bring them up-to-date, they are drifting from the status of live data that are a part of current practice and knowledge to the status of fragmentary historical documents.

Atrophy of land resources information is a consequence of evaporation of demand. Without the *pull* in the shape of demand, the *push* agendas of pedlars of information are unlikely to make progress. A renaissance requires dialogue with the decision-makers, understanding their needs and concerns, and demonstration of the value of better natural resources information. Initiation of that dialogue needs champions armed with a compelling analysis of alternative natural resources strategies but there is no magic wand to put things right: resurgence of knowledge of the land requires a career structure, education and training for a new cadre of natural resources specialists. It will take a generation if we start now.

'If you keep on telling the truth, sooner or later you'll be found out.'

Oscar Wilde

Chapter 1

THE CONTEXT

'Man masters nature not by force but by understanding. That is why science has succeeded where magic failed: because it has looked for no spell to cast over nature … we control her only by understanding her laws.'

The Common Sense of Science Jacob Bronowski 1951

Security, assured food water and ecosystem services are interdependent. Policy makers face competing claims on finite land and water, declining crop yields, costlier energy and fertilizers, land degradation and water scarcity, diminishing biodiversity, and climate change. But the land resources information needed to support policy and management decisions is not there any more.

1.1 Land resource issues

We all depend on natural resources: air and water, land and soil. We need fields, orchards and plantations to produce food, fibre, timber and pharmaceuticals. At the same time, we need natural forests, wetlands and rangelands that maintain ecosystem services: regulation of the water, carbon and nutrient cycles; disposal of wastes; and renewal of soil fertility. These services are irreplaceable - and taken for granted (Daly and others 1997). Since the Brundtland Report, in 1987, governments have paid lip service to sustainable development that 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). We can point to individual success stories but major environmental trends continue to deteriorate (UNEP 2007). Below, we discuss a number of colliding issues that are putting policy makers are under pressure.

1.1.1 Burgeoning demand

The world now supports more than three times as many people as at the outbreak of the First World War. World population is projected to increase from 6.9 billion people today to 9.3 billion by 2050 (UN 2011) and demand for food is likely to surge by 70 per cent globally and 100 per cent in developing countries, compared with 2009 (FAO 2011).

1.1.2 There are no reserves

All this production must come from the same land and water resources or, if present trends continue, much less; there are no great reserves to draw on.

Beginning in the 1960s, the *green revolution* carried food production ahead of the population curve; average yields of major crops more than doubled over a few decades thanks to the application of cheap power, fertilizer and irrigation to new, high-yielding crop varieties. Over this period, the cultivated area increased by 12 per cent through a doubling of the irrigated area; while the area under rain-fed crops actually declined (Fischer and others 2010, Figure 2). The area under cereals peaked in 1981, grain production *per caput* peaked in 1987 and the total extent of arable peaked around 1991 (Figure 3). New wealth has brought increasing demand for meat, so more and more grain has been diverted to stock feed and, more recently, significant areas are being turned over to the production of bio-fuel.

Figure 2: Areas of land under rain-fed and irrigated crops (FAOSTAT 2010)

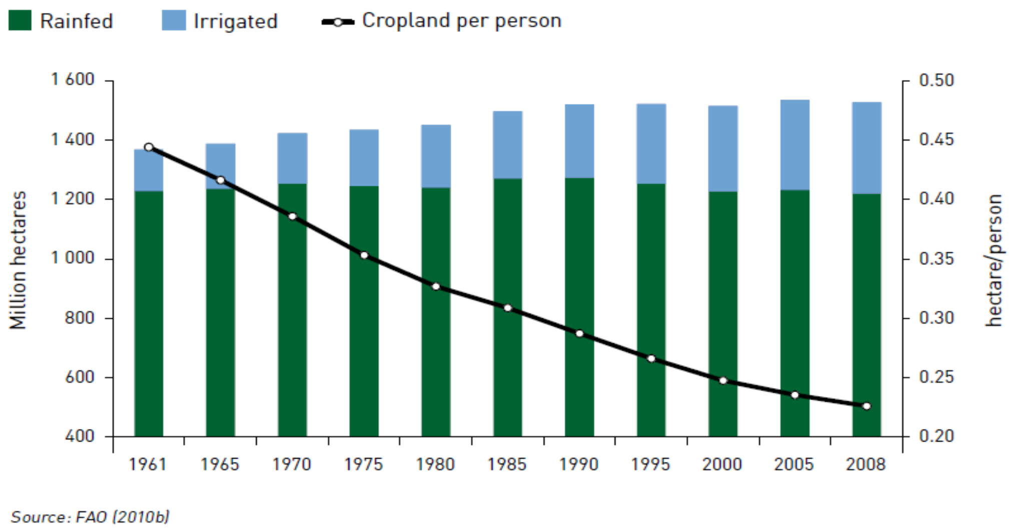
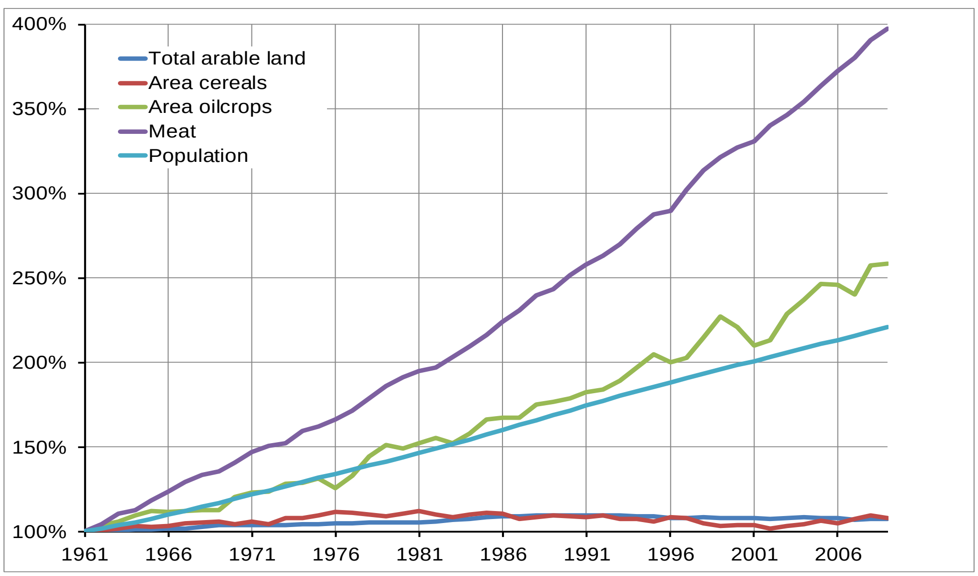


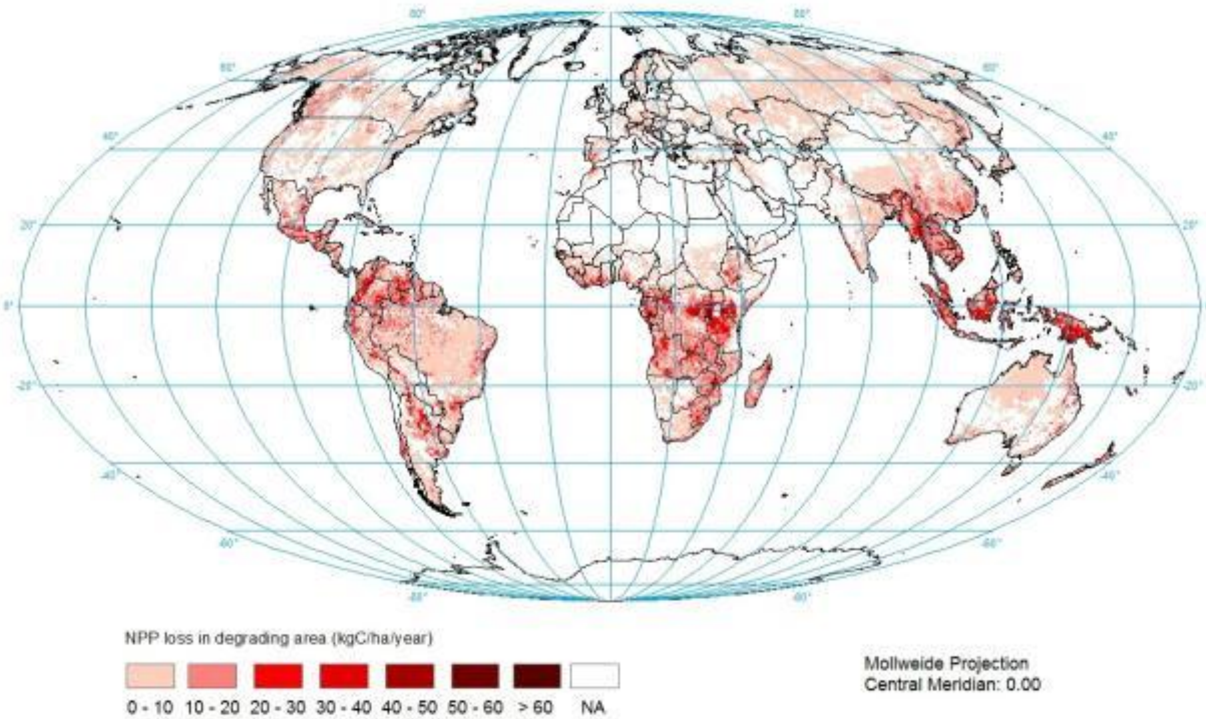
Figure 3: World population, cultivation and meat production 1961-2009 (FAOSTAT 2010)



1.1.3 Land degradation

On top of historical land degradation going back 10 000 years in long-settled areas, one quarter of the land surface has been degrading over the last quarter century (Figure 4); one third of forests and one quarter of the arable land. Africa south of the equator, SE Asia and south China are hardest hit, but this is not just a problem of developing countries - every continent and every biome is afflicted.

Figure 4: Proxy assessment of land degradation as loss of net primary productivity from degrading land 1981-2006 (Bai and others 2008)



Apart from destruction of vegetation and erosion of the soil itself, insidious aspects of land degradation include increased soil acidity, salinity and sodicity, and loss of humus, soil structure and biodiversity. The trends depicted in Figure 4 are almost certainly underestimate the degree of degradation. Nearly all farming systems are running down stocks of soil organic matter that supply plant nutrients, maintain infiltration, available water capacity and resilience against erosion, and fuel soil biodiversity; but production may be maintained till a tipping point is reached and then the system flips – like the Dust Bowl in the Prairies of the USA in the 1930s when the black earth turned to dust[1]. This is happening now: in a single event, in 2007, three million tonnes of soil took off from Southern Ukraine in a dust plume that deposited thousands of tons in Kent (Brimli 2008).

In short, the food system is unsustainable. Fuel and fertilizer are no longer cheap. Water resources are over-allocated in all the main food producing areas. The spectacular yield increases of the green revolution have tailed off; in some places they are decreasing. And current farming systems are driving land degradation. If we carry on using resources as we do now, by 2050 we will need the equivalent of more than two planets to sustain us (European Commission 2011).

[1] Lal (2004) estimates 82 per cent of terrestrial carbon is soil organic matter. In temperate regions, soil loses 30-50 per cent of the native carbon within 50 years of cultivation; 10 years in the tropics. In the last century, 60 per cent of soil and biomass carbon has been lost through land use change; the current loss of about 1.5billion tons/year is a significant proportion of greenhouse gas emissions. Cultivation of peatlands, such as those in SE Asia converted to produce palm oil as bio-fuel, also creates a big soil carbon debt (Fargione and others 2008). During the 20th century, the best soils in the world, chernozem, lost 30-40 per cent of their organic carbon (c40 tonnes/ha); under bare fallow, losses are 80 tonnes/ha in 50 years – yet yield abundantly till they reach their tipping point (Krupenikov and others 2011).

1.1.4 Climate change

Sustainability has to be achieved while coping with climate change. By 2030, global reduction in crop yields may be as much as 3-15 per cent for maize, 2-14 per cent for wheat, 1-3 per cent for rice, and 2-7 per cent for soybean (Lobell and others 2011), but there are important regional differences. In Australia, production of major crops is expected to decline by 9-10 per cent by 2030 and 13-19 per cent by 2050, slashing exports by 11-63 and 15-79 per cent, respectively (Gunasekera and others 2007). IFPRI projects a fall in wheat yields in S Asia of 44 per cent by 2050 in the absence of effective mitigation measures; half of India's high-potential wheat production area may become heat-stressed, lower-potential, short-growing-season cropland and for every degree Celsius rise in mean temperature, wheat yields in India are likely to fall by 6 million tonnes/year costing $1.3 billion/year at current prices (Swaminathan 2011).

1.2 Policy failure and market failure

There is broad consensus that that global security depends on food and water security. And, yet, land resources are the policy-makers' blind spot; the benefits and costs of the environmental services that underpin society do not even enter the economic calculus. Loss of natural capital is not accounted in the price of production; it is handed on to future generations as farmers and loggers in many areas repeat the cycle of degrade > abandon > migrate, leaving a legacy of dust clouds, landslides, choked reservoirs and stream channels, and greenhouse-gas emissions.

The issues have been well flagged. As early as 1968, one of the leaders of the green revolution warned:

> '*Initiation of exploitative agriculture without proper understanding of the various consequences of every one of the changes introduced into traditional agriculture, and without building up a proper scientific and training base to support it, may lead to an era of agricultural disaster in the long run, rather than an era of agricultural prosperity'* (Swaminathan 1968).

More than 25 years ago, the Brundtland Report called for scientific assessment of the Earth's capacity to support human needs and for action to meet these needs without compromising the capacity of future generations to meet their needs (WCED 1987). Since the Rio Earth Summit in 1992, there has been a procession of initiatives: the International Board for Soil Research and Management (IBSRAM)[2], the CGIAR Challenge Program on Water and Food [3], EU Soil Protection Policy, the Millennium Goals, the Millennium Ecosystem Assessment (MEA 2005). None has made any measurable impact on the ground in the face of disinvestment in food and agriculture, development assistance and knowledge of the land.

The food price spike of 2007/8 and subsequent price volatility have concentrated minds on food security (Royal Society 2009). Recently, in the UK, the All-Party Parliamentary Inquiry into Global Food Security (APPG 2010) predicted 'a perfect storm of global events' from collision of ever-growing demand for food, energy and fresh water, the stresses of climate change, destabilisation of governments that cannot provide people's basic needs, and increasing migration from poor countries to those better endowed. These are chronic issues in the Middle East, central and south Asia, Central America and Africa that have boiled over in food riots and revolution. The inquiry concluded that, after decades of neglect, '*we must use every tool in the bag'*. Other calls for action embrace land use planning, spread of best practice, innovation, and capacity building (*e.g.* NEPAD 2010, Montpellier Panel 2010, FAO 2011, UNCST 2012).

[2] For IBSRAM research reports, see http://www.nhbs.com/browse.php?pub=1039

[3] See: http://waterandfood.org/

Adaptation to climate change surely demands climate-smart land and water management. Two candidates that are adaptable to local ecosystems, cultures and market demand are: drought-proofing soils by c*onservation agriculture,* and *precision agriculture* tailored to each facet of the landscape.

- *Conservation agriculture*[4] involves minimum tillage or no till, permanent organic soil cover and diversification of crops grown in rotation or associations. In concert, these practices build resilience by putting organic matter back in the soil; protect the surface from baking sun, rain and wind; stabilise soil structure, increase infiltration and cut destructive runoff; control weeds and pests; and increase crop yields (Kassam and others 2009, Krupenikov and others 2011, FAO 2013). Commercial farmers often use herbicides to control weeds but crop rotation, mulching and no-till also control weeds and pests. Conservation agriculture has been adopted over some 125million ha, expanding at about 8 million ha/year (Friedrich and others 2012) but farmers are having to learn as they go. Faster uptake and improvement needs sustained policy and institutional support.

- *Precision farming* means adapting farm operations to every facet of the landscape, taking advantage of natural variation - rather than ignoring it and compensating with blanket application of agro-chemicals and brute force - which depends on much more detailed land resources information than is generally available.

This is 'high farming' and demands a high level of knowledge of the land. Movers and shakers usually assert that necessary science and information is to hand. Not so. A wealth of knowledge was built up during the Golden Age of land resources surveys from 1945 to 1975 but, when the going was good, political attention turned elsewhere and the knowledge infrastructure of land resources and land use planning was neglected. The legacy data are being lost along with the expertise needed to interpret them. In any case, most of our information is more than thirty years old and collected for different purposes and with different assumptions than today's: the world has changed and no one can pretend that land resources information has kept pace. There are big gaps in existing land and water resources databases; land resources audits that include assessment of ecosystem services are needed for informed decisions on development options; and new research on existing farming systems is essential to develop ways and means of conservation and intensification.

Some recent, prominent reports highlight the need to rebuild human and knowledge capital. In the United Kingdom, the All-Party Parliamentary Group on Agriculture and Food for Development (2010) drew attention to the decline of the knowledge base and the cadre of specialists in natural resources; and the *Foresight* report (2011) calls for improvement of the evidence base upon which decisions are made and for development of measures to assess progress (Box 1). In the international arena, FAO (2011) has identified three areas where much greater investment is needed to win food security: *public goods* like roads and land and water protection works; *institutions* promoting sustainable management, research and development, and regulatory systems; and *knowledge-based, integrated planning* of land and water investments. But no champion has emerged for the knowledge itself. Out of the 283 paragraphs summarising the *Rio+20 UN Conference on Sustainable Development* (UNCSD 2012), there are but three glancing references to land resources information:

- 'Strengthening the three dimensions of sustainable development' (on which the signatories are resolved) 'will, *inter alia* (76g) promote the science-policy interface through…access to reliable, relevant and timely data in areas relevant to sustainable development'

[4] Otherwise known as *ecological agriculture*

- Under Food security and sustainable development (114): ‘We resolve to take action to enhance agricultural research, extension services, training and education (and) improve access to information, technical knowledge and know how’

Box 1: The Future of Food and Farming

The Foresight report, *The Future of Food and Farming* (2011), emphasises that ‘substantial changes will be required to live with climate change and achieve food security for a predicted nine billion people’. It argues for integration of environment and development as cornerstones of a green economy. This will depend on ‘the spread and implementation of existing knowledge, technology and best practice, and investment in new science and innovation and the social infrastructure that enables food producers to benefit from these’. Specifically, the report advocates ‘reversing the low priority accorded to agriculture’. As well as the usual favourites like crop breeding, it argues for ‘revitalisation of extension services’ and ‘priority investment in soil science and related fields that have been neglected in recent years but which offer better understanding of the constraints on productivity and management to prevent further land degradation, cut pollution and emissions of greenhouse gases, and maintain ecosystem services’.

- Under Technology (274): ‘We recognise the importance of space-technology-based data, *in situ* monitoring and reliable geospatial information… and note the relevance of updated mapping and global environmental observation systems (and) the need to support developing countries in their efforts to collect environmental data.’

1.3 As the decision makers see it

Access to relevant land resources information is not enough for evidence-based decision making. Decision-makers have to balance a wide range of interests and are subject to many influences, of which knowledge of the land is only a part. And knowledge is not value-neutral; much is contested, different groups attach different weights to it, and some knowledge providers are more credible and respected than others. For instance, an NGO activist would be more likely to listen to farmers’ concerns about environmental impacts of agribusiness expansion than a private investor in such businesses; and we note in the Australian case study how beleaguered state scientists do not necessarily take kindly to new-fangled ideas proffered from outside, especially from Canberra.

To raise the profile and use of land resources information in decision-making, we need to understand how knowledge, policy and power interact to promote or prevent change. Knowledge may play many parts – both anchoring policy discussions and decisions in an understanding of the world and challenging policy-makers and decision-takers to think more broadly about what could be achieved. Jones and others (2012) elaborate four factors that determine how these roles are fulfilled and the way in which knowledge is ultimately used (our illustrations in italics):

- The **political context** of the policy process, whether it is at a particular scale or under a certain kind of regime *(Who has the strongest voice? Are there checks and balances to ensure that weaker voices can be heard, for example procedures that allow the concerns of local communities to be taken on board?)*

- The relative strength and interplay of **participants' interests, values/beliefs and credibility** (*How do the interests of the various participants coincide or conflict? Are there strongly held values and belief systems which affect this? Who has credibility? Who is influenced by whom?)*

- The **kinds of knowledge** that are sought and generated *(What kinds of knowledge are used in policy debates and in decision making? Where does this knowledge come from? What kind or source of knowledge is paramount?)*

- **Knowledge interaction processes** that mediate between sources of knowledge and policy decisions; people or organisations that translate knowledge into more accessible formats, for example NGOs simplifying maps for use in participatory planning with rural communities *(Are there organisations or individuals that specifically work across the interface between knowledge and policy? How do they work and what effect do they have?).*

Appendix 1 is a diagnostic to assess the status of use of land resources information. It covers both the political context and the participants, as well as specific questions on land resources information.

Not likely to be heard from any recent President of the USA:

'The nation which destroys its soils destroys itself.'
Franklin D Roosevelt

Chapter 2

LAND RESOURCES INFORMATION

The public reaction to a new truth has three stages: 'it's not true', 'it's contrary to scripture', we knew it all along'.

2.1 A short history

Systematic information on natural resources dates from the age of empire. In the decades after the Second World War, urgent demand from decision-makers created a golden age of land resources surveys that underpinned development policy, land use planning, and the green revolution that more than doubled cereal yields in a few decades from about 1965. But in the years of plenty, the attention of governments turned elsewhere; demand for land resources information evaporated and institutional capacity was run down.

Research on tropical products began in botanic gardens in Europe in the 16th and 17th centuries; the first tropical garden, the Pampelmousse in Mauritius, dates from 1735. The founding of the royal gardens in Kew, in 1759, marked the onset of a prolific period of applied research; colonial powers established chains of tropical gardens, especially in the nineteenth century. By 1900, Kew alone had 700 men in the field, not only transferring plants but also investigating ways of using them. Tropical research institutes were established in home countries and colonies: in London, the Imperial Institute was founded in 1896 and departments of agriculture overseas, for example in India in 1881, Barbados in 1898 and Trinidad in 1922. The Royal Tropical Institute in Amsterdam, founded in 1910, was pre-dated by several research stations financed by estates in Java and Sumatra. Similar networks linked French, Portuguese and Belgian domains.

2.1.1 Early surveys

The priorities for colonial development were surveys to find the best places, research to find the best methods, pilot schemes to find ways of using them, and contacts to find markets. Planning and professional science had limited impacts because they emerged 'in an age in world history when colonialism itself began to lose its prestige' (Gaitskell 1964); big development schemes also came late in the day. The result, at independence, was a dual economy: one sector made up of commercial farmers (such as cocoa farmers in Ghana and settler estates) highly specialised in the production of cash crops for export; the other, most of the population who remained subsistence farmers. The two sectors remain poorly connected, even today.

Where settlement was encouraged, for example in Algeria, Tunisia, Kenya, Southern Rhodesia and South Africa, demand for surveys increased in the 1930s as colonial administrations sought to identify suitable land for settlement and plantations. Information was also needed to deal with soil erosion, to identify land free from tsetse fly, and to set aside forest reserves. At this time, there was very little information on natural resources; even topographic surveys were mostly involved with plans for registration of title, although the triangulation of several territories was completed in the 1930s.

Early land resources surveys were accomplished on a shoestring and with few staff; for example the reconnaissance survey of the Belgian Congo (Baeyans 1938), a soil map of central Nyasaland (Hornby 1938), and the *Provisional soil map of East Africa* (Milne 1935/6). Milne introduced the soil catena as a mapping unit and this became the basis for later integrated surveys. The earliest and some of the best examples of integrated survey were the vegetation and soil surveys of Northern Rhodesia by Trapnell and others (1937, 1943, 1948) - helped by the fact that most of the country still carried semi-natural vegetation which is a sensitive indicator of the environment; the legends incorporated landforms and soil-vegetation units and the reports included relevant detail on farming systems. Also in this period but in a different context, soil surveys began in the USA at a scale of one inch to the mile. *Soil Types* were mapped according to topsoil texture and grouped into *Soil Series* according to the parent material. Their practical value was soon proven and establishment of a strong institution (the Soil Conservation Service) in response to the calamity of the Dust Bowl in the 1930s secured the methodology (Kellogg 1937) and, subsequently, the completion of detailed survey of the whole of the USA except Alaska.

The *mapping out* procedure applied in Ceylon from 1935 (Box 2) marked the beginning of land use planning in response to the needs of the burgeoning local population.

Box 2. Mapping out in Ceylon

Under Land Development Ordinance 19, 1935, *Mapping-out Officers* of the Survey Department were responsible for earmarking land for:

- Village expansion, forest, pasture, *chena* cultivation and other village purposes;
- Colonization, alienation to middle-class Ceylonese, and to any purpose irrespective of class or race;
- Protection of sources and courses of streams and prevention of soil erosion;
- Forest reserves, archaeological reserves, fauna and flora reserves;
- Government purposes, requirements of local authorities, development of towns and other prescribed purposes (*e.g.* mining and gemming).

Village headmen had to complete a schedule of village needs, specifically: population in the last forty years; areas of paddy and upland gardens owned by villagers; numbers of buffalo and cattle; localities of crown lands used to obtain timber and other forest products; crown lands suitable, or ever used, for paddy and lands that could be restored; crown lands used for *chena* cultivation at any time; streams upon which paddy lands depend, whence they rise and traverse; and sources of water supply.

Mapping-out officers were to check this information in the field, consult the Divisional Forest Officer about preservation of forest, the Department of Agriculture on land suitable for farming, and the Irrigation Department about irrigation facilities, and draw up a coloured plan of actual and recommended land use on village plans (scale 1: 3 168) or record diagrams (scale 1: 12 672). The Government Agent was empowered to appoint an advisory committee of five persons not in government employ and take representations from the public before submitting an agreed scheme to the Land Commissioner for gazetting.

For implementation, surveys were to demarcate reservations and land for settlement. For village expansion in the wet zone, one-acre lots were to be provided and a *land kachcheri* held to receive applications and allot land, which was to be staked out on the ground and a plan prepared for registration and for the recipient; blocks of 20 acres were allocated to the middle class for plantation crops. in the dry zone, colonisation schemes were organised, the usual allotment being five acres of irrigated land and three acres of upland.

Dalal-Clayton and Dent 2001.

Elsewhere in the British sphere, development planning began in the period 1943-45. For example, the

Government of Kenya put forward a plan for soil conservation, water supply and housing with plans foreshadowed for forest plantations, education and construction. In the words of the Governor: ‘Land, water, forests, and roads are necessarily the key words in any development plans which are formulated for Kenya: progress and development in other directions must inevitably depend to a large extent upon the development of the chief natural assets of the colony – land, water and forests – and an improved road system is necessary before these resources can be developed and exploited’ (File 38557, Kenya 1943 (CO/533/530) item 10, Despatch no. 112). Another despatch to colonial administrations in 1945 required preparation of development plans and drew attention to the advantages of regional schemes and the need for a proper balance between development and welfare. Plans were made to undertake topographic and geological surveys throughout the colonies, supported by aerial photography by the RAF.

2.1.2 The Golden Age

In the aftermath of the Second World War there was an enormous demand for topographic, geological and land resources surveys – and big blank spaces on the maps to be filled. The spectacular failure of the Tanganyika Groundnut Scheme in 1947-49 (Box 3) became a touchstone for land resources surveys worldwide.

Box 3: The Tanganyika groundnut scheme

In the years after the Second World War, all Europe was hungry. In 1946, Frank Samuel of the United Africa Company (UAC) proposed a scheme to grow groundnuts over 5 million acres of ‘empty spaces’ in East Africa. Attracted by the idea, the British government appointed a three-man team to establish whether the land was suitable, whether there were insuperable objections on grounds of native land tenure, and how soon the necessary agricultural machinery could be procured. After nine weeks in the field, the investigators recommended mechanised clearance of 3.3 million acres over six years to secure an annual production of 600 000 tons of groundnuts on 30 000 acre farms.

Even before the mission, advisers warned that half the area was dry and that soil surveys were needed. These doubts were raised again but the government approved the scheme in its entirety, to be implemented ‘at full speed’ by UAC until a new government body, the Overseas Food Corporation took over. The areas chosen in Tanganyika were 450 000 acres in Central Province (Kongwa), 300 000 acres in Western Province (Urambo) and 165 000 acres in Southern Province (Nanchingwea); with 300 000 acres in Kenya and 100 000 acres in Northern Rhodesia. As part of the scheme, a railway was to be built from the new deepwater port of Mtwara. A UAC memo in January 1947 stated: ‘The urgent need for progress, dictated by the need to have a crop in the spring of 1948, has rendered it impossible to enter the scheme on a fully planned basis.’ Second-hand machinery was procured - bulldozers from American army surplus and Canadian tractors. Bush clearing began in April but progress was slow; machines broke down, it was hard to extract the long roots of the native vegetation, abrasive soil blunted the ploughs, compaction rendered the soil unsuitable for groundnuts, there were weed and drought problems: the first crops, at Kongwa, are said to have been less than the seed put into the ground.

In 1950, the Director of Soil and Land Use Surveys in the Gold Coast, Cecil Charter, was brought in to put things right. After a month in the field, he concluded ‘Some of the more fundamental tasks that should have been accomplished earlier appear to have been neglected or overlooked, notably the identification of soils, determination of their distribution and assessment of their value, and … the handling of the difficult and inherently structureless soils of the uplands on which the majority of the groundnuts will be planted.’ He then demonstrated what had been neglected with a comprehensive survey: climate, geology, the distribution and characteristics of the soils (in particular quartzite stone lines reinforced by iron concretions, and angular quartz grains that rasped plough discs and packed to a macadam surface under the weight of heavy machines), the difficulties of large-scale mechanised cultivation and 'the experimental character of the groundnuts scheme ... It seems obvious to me that the scheme cannot continue along its present lines with any prospect of success.' Young (2007) remarks 'The Tanganyika Department doubtless derived much benefit from his advice but one suspects that they might not wish to invite him again.'

In January 1951, the Cabinet wrote off a loss of £36million; the rump project was rationalized as a 'scheme of large-scale experimental development to establish the economics of clearing and mechanized, or partly mechanized, agriculture under tropical conditions' (Cmd 8125m 1951, quoted by Morgan 1980). Further drastic revision followed and in 1954, as a salvage operation, the assets were transferred to a newly established Tanganyika Agricultural Corporation. Activities at Kongwa concentrated on cattle and pasture improvement with one arable farm continuing mechanized agriculture – this was discontinued in 1957. The Urambo area became a tenant farming and settlement scheme but reverted to subsistence cultivation. Nachingwa remained in large-scale, mechanized production of soya, groundnuts, maize and cashew but was, eventually, abandoned.

After Dalal-Clayton & Dent 2001.

The failure of the Groundnut Scheme highlighted the need for soil and land resources survey prior to development and guaranteed their place in development planning for a generation. The simple conclusion - that any development located on unsuitable land can never succeed - has been reinforced time and time again. The objectives of surveys were expressed by Ernest Chenery's proposal for a soil, vegetation and agricultural survey of Uganda in 1954 (quoted by Young 2007): 'A background to assessing the present and future agricultural potential of the Protectorate, and its viability for capital investments … [and specifically] the allocation of foreign aid.'

Surveys followed one of two tracks. One was the American model of detailed field survey and laboratory analysis with the *Soil Type* or *Soil Series* as the mapping unit (Soil Survey Staff 1952). Following the Dust Bowl catastrophe in the 1930s, leadership at the highest level and a strong institution that wanted the maps (the Soil Conservation Service) ensured that the whole of the USA except Alaska was eventually mapped at scale 1:20 000. It was accepted that information was needed at the field level for the layout of irrigation schemes and in thickly settled countries; for instance, the Soil Survey of England and Wales adopted a field scale of six inches to one mile (1: 10 560) but the job was never finished.

In contrast, where new lands were to be opened up, early surveys were unashamedly reconnaissance. Many advances were driven by the need to cover the ground quickly and, at the same time, recognition that the details mattered. In Northern Australia, CSIRO pioneered surveys of *land systems* - recurring patterns of landforms, soils and vegetation that could be identified and delineated on air photos (Christian and Stewart 1951). The land system might be subdivided into *land facets* - mappable (though not usually mapped out) entities of uniform landform, soil and vegetation. Land systems survey depends on presumed correlations of landscape features observable by remote sensing; field observations are not, primarily, to locate boundaries on the ground but to identify soils and vegetation within areas delineated on air photos. Another premise is that most land uses are constrained by the combined and interacting effect of several land attributes – so the same map can be interpreted for many different purposes. During this period, surveys were transformed by the application of photogrammetry to topographic mapping, and air photo interpretation of land use, vegetation and soils. With the launch of Landsat 1, in 1972, air photos were supplemented by satellite imagery that has provided a regular and ever-more-detailed global perspective.

Ideas about development were uncomplicated: identify where it should work and where it wouldn't (eliminate the mountains and swamps); put in the roads, bridges and water; establish settlements on suitable land; and leave them to it. Early land resources reports generalised field data for each land system and added a physical overview that drew attention to opportunities and limitations for development; examples include land systems atlases of Lesotho (Bawden and Carroll 1968), Uganda (Ollier and others 1969), Swaziland (Murdoch and others 1971) and part of Kenya (Scott and others 1971). A later sequence of land systems surveys in Nigeria culminated in seven substantial volumes on Central Nigeria with a clear focus on development opportunities (Wall and Hill 1975/6). Not a lot of development seemed to result from these inventories but, where there was already momentum for development and surveys were carried out in conjunction with the civil engineers who were building the infrastructure, land resources surveys made a big contribution, for instance in the Jenka Triangle in Malaya (HTS and TAMS 1967, World Bank 1987) and the Mahawelli power and irrigation project in Sri Lanka (HTS 1980/81).

There was substantial support for land resources surveys from specialist agencies of the United Nations, notably FAO which, itself, had 300 surveyors in the field in the 1970s and, for decades, also operated a well-respected 'associate experts' scheme to blood young professionals. This period also saw expansion of international aid agencies; some like the Land Resources Division of the UK Directorate of Overseas Surveys evolved from colonial administrations, others were newly created (*e.g.* DANIDA, FINNIDA, NORAD and Sida in the Scandinavian countries). Assistance was given to re-vamp run-down survey and planning organisations or establish new ones, for instance NORAD support for the Zambia Soil Survey (see Zambia case study). Expatriate professionals introduced the latest methods and techniques; and counterparts were sent to Europe and North America to be inducted in these new approaches, which they applied on their return if the required facilities were available.

There was exponential growth in aid-funded rural development projects. Donors usually required baseline resource assessments but appreciation grew that land evaluation was not a sufficient basis for development; it was also important to understand the constraints faced by farming systems. So increasingly complex, integrated surveys were undertaken by combined teams of specialists in various disciplines - examples include LRDC surveys in The Gambia (Dunsmore and others 1976) and in Indonesia (LRD 1985/9), and the Canadian-funded inventory of Nepal (Kenting Earth Sciences 1986). Beyond land evaluation, attention was paid to land tenure, markets, agricultural economics, the structure and financing of enterprises and, even, the structure and workings of societies. But governance and the critical issue of local capacity to marshal, understand and act upon the information were touchy subjects in newly independent countries.[5]

The Green Revolution was a fruit of the Golden Age - and its nemesis. From about 1965, the introduction of new, high-yielding crop varieties combined with cheap fertilizer, irrigation and mechanisation in those areas suited to the new technology, carried global food production ahead of the population curve and appeared to transcend differences in soil and climate (Pinstrup-Andersen and others 1999). Amid the social and political uncertainties of the 1970s and 1980s, its early successes allowed political attention to turn away from natural resources.

[5] The evolution of land resources assessments is illustrated by the case studies of a commercial company, Hunting Technical Services, and the Land Resources Division set up within the British Department of Colonial Surveys and subsequently operated in the post-colonial world within various ministries dealing with overseas aid.

2.1.3 The Age of Uncertainty

The first lesson learnt in the early post-war period was that natural resources surveys are an essential basis for rural development. The second, recognised some thirty years later, was that they are not sufficient (Young 2007). Development turned out to be not so simple as we had thought. Some of the goals of development now seem illusory; the constraints more and more intractable; and the contribution of natural resources information disappointing in the absence of ways and means of using it or, to be frank, in the absence of effective institutions.

The shift in perceptions may be traced through three international conferences. In 1972, the Stockholm Conference on the Human Environment made a link between underdevelopment and environmental degradation; an environmental movement gathered momentum but without much understanding of the natural resources under threat. The Brandt Report, in 1980, defined the North-South divide between rich and poor countries and the growing gap between them. Finally, the Brundtland Report (WCED 1987) came up with a new mantra - sustainable development - to square the vicious circle of poverty and land degradation.

The Sahelian droughts of the late 1960s and early '70s, and the drought in the Sahel, Sudan and Ethiopia in the 1980s (seen on television screens across the world) brought political pressure for action. The old approach of single-issue, technical solutions (like soil conservation) was deemed to have failed but it proved hard to pin down what *was* needed to secure sustainable development. Siren voices called, first, for integrated rural development programs (IRDPs). The concept was to tackle the needs of development through mutually supportive components: for example a combination of improved agronomic practices, credit, development of roads and water supply, sometimes clarification of land tenure. A baseline survey of natural resources was often part of the package. Many of these ideas are embedded in the philosophy of sustainable development but IRDPs foundered on the rocks of institutional capacity.

There were some success stories (*e.g.* Mellors 1988) but most programs were shopping lists of essentially separate projects and integrated in name only. Staff responsible for each component may have executed their responsibilities professionally but it proved hard to combine their skills to achieve broader objectives. And they depended on donor funding; they may have intended to work with and through local institutions but they were implemented through autonomous project bodies and came to rely on autonomy to achieve their objectives. In several cases known to us, all activity ceased when external funding was withdrawn; no perceptible impact remains in terms of land use patterns or practices; they sank without a ripple.

Thanks to the application of science and technology in the developed world and the green revolution in populous parts of the developing world where conditions were favourable (Pinstrup-Andersen and others 1999), the world had never been so rich or so well fed. Even so, the colonial and central planning strategy of large projects dependent on transfer of technology from the developed world - what Gleave (1987) called 'the big push' idea - was found wanting in more difficult cases; often unsound because of false assumptions and lack of local knowledge; often ignored because it did not address local needs. Western governments, reeling under the OPEC oil price hikes of 1973 and 1979, decided that the nuts and bolts of development were not their business, neither at home nor, certainly, overseas. They turned to markets to deliver their aims and gave the recipients of much-reduced aid budgets what they wanted – which was cash, not surveys. Funding for surveys and land use planning dried up and institutions were run down. The residual natural resources budget was diverted to the social sciences: participatory rural appraisal, indigenous knowledge, equitable access to resources, institutional coordination and governance.

To some extent, attention was also transferred to the environmental agenda. The salutary lesson of the Groundnut Scheme translated as 'no development funds without natural resources survey': post-Brundtland, release of funds was linked to preparation of an environmental action plan. Spurious activity ensued under the umbrella of National Conservation Strategies following publication of the World Conservation Strategy (IUCN/WWF/UNEP 1980), and Environmental Action Plans initiated by the World Bank in 1987. Water master plans were also drawn up in several countries, for instance in Bangladesh where the international response to the catastrophic flooding in 1987 and 1988 led to the Bangladesh Flood Action Plan, funded by a various donors coordinated by the World Bank. It was launched in 1990 as a series of regional studies to identify appropriate action but what emerged focused on flood control, did not deal with inter-regional issues (and huge amounts of water move through Bangladesh), and suffered from a lack of reliable baseline data (Hughes and others 1994). Many of these national and sectoral plans overlapped in subject and geographical scope; analysis of documents from any one country that has undertaken more than one of the different processes reveals that each exercise has used essentially the same set of old, inaccurate or suspect data (Dalal-Clayton and Dent 2001) which did not improve the quality of decision-making.

Agenda 21, one of the accords of the 1992 UN Conference on Environment and Development in Rio de Janeiro (UNCED 1992), urged countries to develop a national strategy for sustainable development. The Rio conference also gave birth to three international conventions: the UN Convention on Biological Diversity (UNCBD), the UN Framework Convention on Climate Change (UNFCCC) and, a couple of years later, the UN Convention to Combat Desertification (UNCCD). The first has maintained the international profile of biodiversity. The second, briefly, transformed the global agenda through the activities of Intergovernmental Panel on Climate Change (actually established by UNEP and WMO in 1988, before the Rio conference). The third, which embraces land degradation and sustainable land management, was allotted negligible resources and has achieved negligible results on the ground.

UNCCD failed to achieve credibility on two counts: oversimplification of evidence, such as local observations of the shifting margin of the Sahara (Lamprey 1988), and of the solutions proposed; and confusion pervading the very concepts of desertification and land degradation. The first global assessment of land degradation (GLASOD, Oldeman and others 1992) was a collation of expert opinion - a map of perceptions, not measurements; its qualitative judgements have proven inconsistent and their relationships with policy-pertinent criteria unverified (Sonneveld and Dent 2007). Prior to the application of satellite measurements (see NDVI applications, below), there have never been any measurements of land degradation beyond the experimental plot. Estimates were extrapolations, often using the so-called Universal Soil Loss Equation (USLE, Wischmeier and Smith 1978) which predicts soil erosion on bare ground according to the erosive force of the rainfall, the amount of ground cover and soil type; no matter that there were no good data for any of these factors, extrapolations were made (*e.g.* Brown and Wolf 1984, Pimental and others 1995) and were easily dismissed (Crosson 1995, 2003).

The Millennium Development Goals (MDGs), adopted in 2000 and intended to be achieved by 2015, aimed to provide more focus to the development agenda.[6] The eight goals provide a guiding framework with specific targets and time frames - but none is concerned with the status of land resources. In 2002, the Johannesburg World Summit on Sustainable Development (WSSD) produced a Declaration and a Plan of Implementation with a commitment to 'Protecting and managing the natural resource base of economic and social development …' intended to reverse the current trends in degradation 'as soon as

[6] The Millennium Development Goals: 1. Eradicate extreme poverty and hunger; 2. Achieve universal primary education; 3. Promote gender equality and empower women; 4. Reduce child mortality; 5. Improve maternal health; 6. Combat HIV-AIDS, malaria and other diseases; 7. Ensure environmental sustainability; 8. Develop a global partnership for development.

possible' through integrated land and water management and protection of ecosystems that provide 'essential services'. It is hard to identify any specific actions to implement this commitment or any change in the downward trends of environmental indicators.

The UN Conference on Sustainable Development in Rio de Janeiro in 2012 (Rio+20) aimed to renew political commitment to sustainable development, and assess progress in meeting agreed commitments and new challenges to sustainable development. Two themes framed the conference: the institutional framework for sustainable development and *green economy*[7] . Disappointingly, the conference report, *The Future We Want* [8], did little more than take note of ongoing activities and continuing challenges; as we note in Section 1.2, it barely acknowledges the role and need for land resources information.

The Age of Uncertainty was marked by spasms of uncritical thinking. Oversimplification of the situation in the field continued unchecked by hard data. Oversimplified analysis suggested naïve solutions; and confusion over the facts and the very concepts of land resources, environment and development brought about disillusion and loss of credibility across the field. To some degree, oversimplification may be explained by a sense of urgency. The urgency is often real but does not encourage attention to complexity – for instance in 1974 the Secretary General of the UN was prompted to declare 'in less than 50 years time … the advancing desert threatens to wipe three or four countries of Africa off the map' (Brabyn 1975). Those countries are still there, greener now than they were then - but still poor.

2.2 Where are we now?

Unquestioned faith in industrialised agriculture; loss of the pull factor and failure of the push by professionals; atrophy of natural resources information despite greater-than-ever needs.

Information reduces risk, so land use policy and management decisions should be based on the best available knowledge. This means, first, awareness that natural resources are a key consideration; then decision-makers need up-to-date land resources information, trust in its quality, and the expertise to interpret it in ways helpful to policy and management decisions.

The Golden Age was marked by demand for just such information at the highest level, not least from the colonies which were seen as guarantors of food security and raw materials. This demand was satisfied by government agencies and private companies but the Golden Age guttered out before many countries achieved national coverage. By and large, governments are no longer seeking this information. Over the last thirty years they have abdicated responsibility for food and agriculture, water and the environment. Policy has been market-led, rather than seeking to support strategic fields of knowledge, and many countries have seen a dramatic decline in the gathering and interpretation of fundamental land resources information, dismemberment of public and private institutions in the field and, consequently, extinction of the pool of expertise. In the developing world, survey organisations depended on external assistance; when this was withdrawn, organizations collapsed without any credible strategy for completion or, even, maintaining existing data.

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[7] The *green economy* has emerged as yet another construction to bring together the different dimensions of sustainable development; others include national sustainable development strategies, MDGs, integrated policy and planning, sustainable livelihood and pro-poor approaches, sustainable urban management, sustainable consumption and production... The green economy approach seeks to unite under a single banner the entire suite of economic policies and modes of economic analyses of relevance to sustainable development. The Republic of Korea is the first country to embrace green growth as a national strategy.

[8] Available at: http://www.uncsd2012.org/thefuturewewant.html

This applies not only to food and agriculture but, also, to the environment - which is no longer high on the political agenda; even climate change, where it has proved hard to secure meaningful action to mitigate the well-understood drivers of unwelcome changes. To some extent, demand has been privatised. On the one hand, there is ever-greater demand from the military, civil aviation and shipping for better and more information on terrain, weather and climate, and a strongly cyclical demand for minerals prospecting and development; so national topographic and geological surveys, meteorological services and their private counterparts have built strong and effective positions in market economies. On the other hand, there has been dramatic falling away of demand for information about renewable natural resources, other than water, which are exploited by fragmented and not-very-profitable enterprises.

The early successes of the green revolution led to unquestioned faith and reliance on industrialised agriculture that depends on technological innovation - genetics, agrochemicals and ever-more-powerful machinery. This has spawned several consequences (Kassam 2011), amongst which the now-disputed notion that traditional, locally-adapted crop varieties cannot respond to inputs like mineral fertilizer. The complete package of modern crop varieties, intensive tillage and application of agrochemicals was believed to be essential to maintain ‘enhanced soil fertility’. Immediate results included loss of most government funding for agricultural research and extension – the food problem was considered solved; and *in situ* loss of traditional, locally adapted breeds of crops and livestock. More insidiously, simplification of production systems and acceleration of the trend to bigger and bigger production units has undermined soil resilience, native fertility, biodiversity, ecosystem services, and rural communities. And, globally, crop yields have levelled off; in the heartland of the green revolution, the Indo-Gangetic Plain, absolute yields and factor productivities and have been falling since the 1980s.

The retraction of government funding for agriculture, food and forestry decimated research and development institutions. The cadre of experts was pensioned off; some took up teaching positions but, without a secure career structure to attract a new generation, education and training in colleges and universities withered. In the United Kingdom between 1945 and the early 1980s, there was a clear purpose underlying strategic investment in agricultural science, and close integration between the activities of ministries and research councils of food and agriculture and overseas development. That knowledge-exchange space has shrunk and the overseas presence all but vanished; agricultural research institutes have been reduced by merger and closure to nine (there were more than thirty before the Second World War) and only two Russell Group universities (Nottingham and Newcastle) retain a credible stake in the agricultural sciences. This leaves blind spots in field-based research, land resources surveys, tropical agriculture, and pest-and-disease management (Crute 2011).

Much the same can be said of all the former colonial powers. The former Soviet bloc maintained formidable institutions to deliver data for central planning. The inheriting states have struggled to maintain this capacity; the greening of Eastern Europe seen on satellite imagery over the last quarter century probably reflects landscapes tumbling down to grass and scrub. In developing countries, where survey and research organisations were set up and funded largely by donor assistance, institutions collapsed when the external funding was withdrawn.

Research funds transferred to international agencies - notably CGIAR institutions but they have abandoned research on production systems to un-funded National Agricultural Services; never involved themselves in land resources survey, land use planning and extension, or information and training beyond their narrow remits; and have not created home-grown capacity in developing countries. International reviews suggest a continuing loss of natural resources expertise worldwide; for instance the FAO *Global Forest Resource Assessment 2010* reports that the number of staff in post, many of them forest experts, has declined by 1.2 per cent per year since 2000. National capacities to gather, maintain and interpret land resources information has declined alarmingly and this impinges on the quality of global and regional assessments of the status of particular resources (Box 4).

Box 4: Some global resource assessments

Fisheries
Every two years, FAO's Fisheries Department produces *The State of World Fisheries and Aquaculture* report - a comprehensive overview of fisheries, aquaculture and associated policy issues. The 2004 report confirmed trends already evident in the 1990s: stagnating capture fisheries, expanding aquaculture output, and mounting concerns for the livelihoods of fishers, the sustainability of commercial catches and aquatic ecosystems.

Forests
FAO has coordinated Global Forest Resources Assessments every five to ten years since 1949. The latest (FAO 2010) is the most comprehensive to date in terms of the number of countries and people involved and, also, in its scope. It examines the current status and recent trends of some 90 variables covering the extent, condition, use and value of forests and woodland. Information was collated from 233 countries and territories for 1990, 2000, 2005 and 2010 and presented according to the extent of forest, forest biological diversity, health and vitality, protective and productive functions of forests, socio-economic functions, and the legal, policy and institutional framework.

Water
The World Water Development Report is published every three years, beginning in 2003, coordinated by UNESCO's World Water Assessment Program involving 26 UN agencies and entities of UN-Water and the World Water Forum (http://www.unwater.org/flashindex.html http://www.worldwatercouncil.org/index.php?id=6). Its overview of freshwater resources provides a series of assessments monitoring changes in the resource and its management and tracking progress towards targets such as the Millennium Development Goals. The 2012 report describes major changes, uncertainties, and risks and their links to water resources; reports the status and the trends of water supply, use, management, institutions and financing; and highlights regional trouble spots. It also deals with gender inequality, water-related disasters, health and the role of ecosystems. UNEP's Global International Waters Assessment(http://www.unep.org/dewa/giwa/) focuses on international or trans-boundary waters - marine, coastal and freshwaters, surface and groundwaters. It analyses current trends and their societal causes, scenarios of the future condition of these resources and policy options.

However, things are different in China, Korea, Brazil and India (Box 5). Land use planning and land survey organisations are alive and well in countries with strong bureaucracies and strong economies, especially where they have long been influential departments of government.

Box 5: Resource survey organisations in India

***National Bureau of Soil Survey and Land Use Planning (**Sources: Dent and Deshpande 1993, www.nbsslup.in)

The All India Soil Survey Organisation was established in 1956 under the Ministry of Agriculture to undertake soil surveys for development programs, initially operating from New Delhi and seven regional centres. In 1958 it was integrated with the Land Use Planning Scheme of the Central Soil Conservation Board to carry out detailed surveys for Major River Valley projects, becoming the All India Soil and Land Use Survey. Further reorganisation in 1969 transferred research to the Indian Council of Agricultural Research (ICAR) while development activities remained under the Ministry of Agriculture. In 1976, ICAR set up an independent National Bureau of Soil Survey and Land Use Planning with a mandate for research in soil mapping, correlation and classification, soil landscape relationships, agro-ecological zoning, and land degradation. In 1978, NBSS&LUP moved to spacious new premises in Nagpur – the geographic centre of India. A Remote Sensing Centre was established in 1982 with the help of FAO/UNDP to apply remote sensing and geographic information systems to land resource mapping.

Early surveys followed the procedures of the USDA - detailed mapping of soil types and series at 1:5 000 and

1:10 000. The move to Nagpur signalled expanded activity with District mapping at 1:50 000 but none of the above made any impression on the sub-continent. Dynamic leadership created a truly national mapping program. Following publication of a field manual (Sehgal &others 1987), all India was mapped at 1:250 000 with reports for each State beginning with West Bengal in 1992 and completed in 1999. The program was made possible by 1:250 000 Landsat imagery and assisted by technical input and training provided through the UK Natural Resources Institute. Surveys began with land systems interpretation of satellite imagery supplemented by geological and topographic maps, also identifying landscape elements; then field survey to identify and correlate soils with physiography along sample strips (7 or 8 across each sheet cutting across most of the elements identified by remote sensing) and regular observations on a 10km grid; finally, transfer of the field maps to 1:250 000 base maps and laboratory analysis of the grid samples and benchmark soils. The legends comprise plain English descriptions of each mapping unit, *e.g.* 'deep, poorly drained, clayey soils, very severe salinity' and the equivalent Soil Taxonomy, in this example *Typic halaquept*.

On completion of the national map attention reverted, in part, to *ad hoc* project surveys at larger scale but, also, throughout the 1990s and early 2000s, moved on to use of land resources data in a District Planning series.

Forest Survey of India (FSI) (Source:www.fsi.org.in)

FSI was established in 1981 under the Ministry of Environment and Forests to assess and monitor forest resources and undertake training, research and extension. FSI succeeded the Pre-investment Survey of Forest Resources initiated in 1965with sponsorship by FAO and UNDP. After review in 1986, its mandate was redefined as:

- Prepare a biennial *State of Forests Report* assessing changes in forest cover in the country
- Conduct an inventory of forest and non-forest areas, develop a database on forest tree resources and prepare thematic maps at scale 1:50 000 using air photos; and function as a nodal agency for collection, compilation, storage and dissemination of a spatial database on forest resources
- Train forestry personnel to apply technologies related to resources survey (remote sensing, GIS, *etc*.)
- Conduct research on applied forest survey techniques and strengthen research and development infrastructure in FSI and State/UT Forest Departments (SFDs) in forest resources mapping and inventory
- Undertake forestry-related special studies/consultancies and custom-made training courses for SFD's and other organisations.

Strength in numbers[9] brings knowledge-exchange space, room for excellence, and new ideas which are handed on to the next generation of professionals. China and Brazil are investing strongly in their own natural resources capacity, including research and extension services, and are now active in overseas development. For example, the Brazilian *More Food* program (embracing financial support, loans and service agreements for the supply of machinery, and provision of expertise) has been extended to Africa following the 2010 Brazil-Africa Dialogue on Food Safety, Hunger Alleviation and Rural Development.

And in a small way and in some countries, new sources of funding have revitalised survey and service organisations, or spawned new ones. For example, the Kenya Forest Service (KFS) was established in 2005 with support from the World Bank and the Government of Finland to conserve, develop and

[9] Relative strength in land resources is reflected in membership of learned societies. Membership of national societies of soil science ranges from China 10 000, USA 6500, Germany 1980, Brazil 900, Australia 725, United Kingdom 700, South Korea 530, South Africa 220, down to Nepal, Tanzania and Zambia that have no registered membership (although a Zambian Society of Soil Science was founded in 1990). The proportions of active and retired members would be more revealing; *e.g*. in Australia, the 2011 stock-take of professionals in post showed a professional cadre of 535 in research and extension.

sustainably manage forest resources and lead the National REDD [10] program. Capacity is being augmented to undertake a national forest inventory, establish national baselines and to monitor carbon stocks as required to implement a REDD program, as well as biodiversity and socio-economic surveys; and KFS is coordinating and supporting other agencies and NGOs in Kenya to design and implement specific forest monitoring and inventory projects.

2.4 Who needs land resources information and what information do they need?

2.4.1 Who? What? Why? Where When?

Natural resources issues are, by and large, policy choices by sovereign governments. Their ministers and senior policy-makers struggle to appreciate what action is needed and what information they require to come to decisions on food, water and energy security and climate change - otherwise we wouldn't have to be doing this exercise now!

First, they have to be convinced that political stability and economic development is underpinned by natural resources and ecosystem services; this argument needs generalised information but with specific examples. Then they need to go beyond mere recognition of the fact to commit the specific physical and financial requirements of every case of investment and change of policy – which needs a head for details and relevant, detailed information. Equally, mechanisms and information are needed to call governments to account and redress - if there is a fuss in the media, action follows.

What is needed is reliable information at the point of decision and in a format that the decision-maker can use – which is most likely to materialise when the supply of information is driven by or closely linked to the decision-making process.[11] Otherwise, decisions are taken in ignorance. Uninformed, poor decisions bring land degradation and so-called natural disasters. The 2010 floods in Pakistan were catastrophic not because of unprecedented rainfall but because deforestation and soil erosion in the catchment of the River Indus have curtailed its capacity to retain rainfall, and because of reckless urban development on the flood plain without provision of holding basins.

- *Policy makers in government, regional and international agencies* need land resources information to deal with social, economic and environmental issues like food, water and energy security, climate change, land scarcity, land degradation, and contamination - which also involves public health. Better information is also needed to assess the effectiveness of policies and programs (to establish baselines, *e.g.* for contaminants, set targets and monitor trends); and to implement trading schemes for carbon, water or salt.

- *Industries* need information to match land use with land capability, implement environmental management systems to comply with regulations and codes of practice, to gain market advantage (*e.g.* through green labelling), and to optimise the use of inputs like irrigation water and fertilizer. Ideally, they want very detailed information - which does not exist in most parts of the world.

[10] Reducing Emissions from Deforestation and Forest Degradation (REDD) is a set of steps designed to use market and financial incentives in order to reduce the emissions of greenhouse gases.
[11] See case studies of Huntings Technical Services and the Land Resources Development Centre

- *Local communities and land managers* need better land resources information so that they can read and appreciate the signs of health or degradation in a landscape (White 1992), improve the quality of land and water management, and target community action.

There has always been a military demand for topographic survey and meteorology, strongly supported by the demands of shipping, aviation, overland transport and public utilities. Oil, gas and minerals industries have consolidated into large, trans-national companies that maintain their own intelligence services and, also, contribute directly or indirectly to public geological survey organisations (see the Australian and Zambian case studies). By contrast, management of renewable resources remains fragmented and relatively, sometimes absolutely, small-scale. Individual farm enterprises rarely have the interest or resources to undertake extensive surveys of soils, vegetation, water resources and land use. And many land resources issues are long-term, national and global. Solutions to issues of land use and management, competing claims on land and water resources and environmental services demand well-informed political leadership - so systematic gathering and management of fundamental information has, in the past, been driven by governments.

2.4.2 How much?

We manage what we measure**.** The key questions of land resources globally and nationally are:

- How much potential arable, forest and rangeland is there, and where is it?
- How much of the potential land is being used for farming and forestry now?
- How much will be available in the foreseeable future?
- How much food, fibre and timber can it produce now and in future?
- What are its water resources and how may they be conserved?
- How much carbon can be feasibly stored in agricultural and forest soils, at what rate can this carbon be fixed, and how permanent is this storage?

And because the production of goods and services is underpinned by natural and managed ecosystems, there is another class of question:

- Are the supporting ecosystems in good health?
- Where are rates of ecosystem change affecting the capacity to produce goods and services?

These questions are hard to answer. The diverse needs for land resources information demand a combination of survey, monitoring and modelling. Some questions can be attempted only with simulation models; for instance, we can assess the likely impacts of climate change and adaptive management using scaled-down climate models and farming system models - but the output depends on measured data for running and validating the models. Usually, the critical issue is to calculate stores and fluxes of water, carbon, nutrients and salts, which requires reliable field measurements from each facet of the landscape and estimates of the rates of change. The most problematic estimates are for the slowly changing variables such as carbon; these estimates can be supplied only by long-term field experiments, which are always under threat.

Market-related policy instruments such as carbon, water and salt trading have given impetus to the search for measurable indicators of the *status* of soils, vegetation, water and climate; *performance*, in terms of land use and production; and *stakeholder interests*, such as property rights and responsibilities that often conflict - for instance, the right to farm a patch of land may conflict with other people's rights to and need for a water supply. But reporting the status of land and water resources is hamstrung by the lack of well-accepted measures of fundamental parameters like vegetation cover, soil fertility, structure, water storage and carbon storage. Tracking change also requires simple kits to measure key indicators in the field; the only important attributes that can be monitored satisfactorily at the moment are salinity (through electrical conductivity) and reaction (pH).

Equally, there is need for ground rules for decision-makers to assess their own performance, the risks of new developments and of continuing with present practices. This needs translation of biophysical measures in terms of natural capital, ecosystem services, and the benefits and costs of different development options. The requirement to report on an agreed set of land and water quality attributes (*e.g.* carbon stores) and processes (*e.g.* erosion, salting) is not 'mindless monitoring': it brings rigour and focus to natural resources policy, planning and management.

At the grass roots, land managers need accurate information at the field scale to take account of local variability and, if possible, take advantage of it. This means information on fundamental attributes like slope gradient, aspect and relative position; drainage status, stoniness, topsoil and subsoil texture, structure, humus content and nutrient retention capacity: information which, at the field scale, is lacking almost everywhere [12].

The hardest tasks for both policy-makers and managers are to test and integrate various strands of information that may be supplied to them though the wonders of information technology. This was an important role of specialist natural resources institutions, which built up a wealth of expertise and institutional memory. Their demise has created a critical gap in the decision-making process.

2.4.3 Soil information as an exemplar

The status of soils information epitomises information about renewable natural resources in general (in fact, most so-called soil surveys were much wider in scope): consistent data are lacking at local, national and global levels. Three primary data sets are the foundation for all other products and services: soil profiles, soil maps, and soil grids:

Soil profiles: descriptive and measured data for individual, geo-referenced observation sites. Profile descriptions include site, soil morphology, and physical, chemical and biological attributes (some measured in the laboratory). Amongst several scrutinised datasets, ISRIC–World Soil Information [13] maintains the ISIS soil information system comprising almost one thousand profiles representing the mapping units of the FAO-Unesco *Soil Map of the World*, comprehensively described and analysed and backed up by a sample archive; and the WISE [14] database of 10 250 profiles abstracted from published survey reports. Various organisations maintain national datasets and sample archives but many are precarious or have been lost.

Soil maps: representations of the soil cover as parcels of land, each categorised in terms of the kinds of soil or combinations of soil and terrain (soil landscapes or land systems) identified by hierarchical

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[12] Resurgent market demand for information on renewable land resources now has few places to turn to. For example, precision agriculture requires very detailed soil information - at the level originally intended but never achieved by the former Soil Survey of England and Wales. Little or no use is made of national soil survey data; instead the industry gathers its own information *de novo* with the help of a 'Dad's Army' of part-timers who learned their trade in now-defunct national soil surveys and international consultancy.

[13] See case study and http://www.isric.org/

[14] World Inventory of Soil Emission Potentials http://www.isric.org/projects/world-inventory-soil-emission-potentials-wise

classifications that are related to observed and measured attributes. Soil maps are skilled interpretations of the landscape and, in the case of land systems surveys, rapid and inexpensive. But their strengths are also their weaknesses. An experienced surveyor may make a perceptive map but it is a personal interpretation; others will produce different maps because the mapping criteria are not explicit and the surveyor's mental model was never recorded - so the map cannot be recreated or updated. Intensities of sampling are rarely enough to test the presumed relationships between the observed landforms and the vegetation and the mapped soil attributes, and reliability is rarely recorded. Coverage is uneven. The latest compilation of global soil information, the *Harmonised World Soil Database* (Nachtergaele and others 2012) is a 30arc-second raster database combining regional and national data derived from some kind of systematic survey but it still has big gaps filled by 40-year old exploratory data from the 1:5 million scale FAO-Unesco *Soil map of the World* . Few countries have matched the USA in achieving consistent, national coverage at a semi-detailed scale (1:20 000 to 1:63 360). Most surveys stuttered to a halt without achieving even minimal coverage at the required level of detail[15] and the status of the legacy data is precarious.

Soil grids: The format of legacy soil maps is incompatible with other datasets that are held electronically; compatibility requires grids of soil attributes creating continuous surfaces, as opposed to discrete parcels of land. Digitising the original soil maps does not overcome limitations of information content and unknown reliability. Digital mapping *de novo*, better described as predictive mapping, depends on rules established through field experience and applied to mapping soil properties; such a map is reproducible and can be updated as better knowledge becomes available. There have been several attempts to model soil distributions on the basis of explicitly stated models using geo-located soil profile data, digital elevation models and inference from other remotely-sensed data, but few (for instance MacMillan and others 2007) have been successful over significant areas. Bob MacMillan (personal communication) comments:

> *'The knowledge-based mapping worked so well in British Colombia because I worked with a really strong local expert who calibrated and refined my initial predictions to match his extensive local knowledge. When I try to apply a similar approach in areas where I lack personal expertise, or do not have access to a strong local expert, the success rate drops dramatically and the level of effort increases as well.'*

Two recent advances have made the creation of national or global grids feasible: open access to the SRTM [16] digital elevation model which provides a uniform, near-global basis for modelling soil patterns; and infra-red spectral analysis of soil samples which has lowered the cost per sample of comprehensive soil chemical analysis from hundreds of dollars to ten. Work is now under way on a regional grid for Africa with detail better than 1km and a calculated index of confidence for each pixel and a global grid under the Gates-funded *GlobalSoilMap* project.

Decision-makers cannot make use of raw data. They have to be interpreted for the decision in hand. Keys may be provided but this information is accessible only to specialists; private individuals are not prepared to pay for interpretations, governments cannot wait, so off-the-peg interpretations were developed. The most widely used are the US Bureau of Reclamation classification for planning irrigation projects (USBR 1953) and the USDA Soil Conservation Service's *Land Capability Classification* developed to indicate the soil conservation practices needed on any patch of land (Hockensmith and Steele 1949, Klingebiel and Montgomery 1961). The simplicity of Land Capability (from class I, best, to class VIII, worst) is attractive to decision makers and has been widely copied, sometimes for purposes for which it was ill-fitted, but the more sophisticated FAO *Framework for Land Evaluation* (FAO 1976) proved too complicated for the planners. American soil survey reports also gave a lead with interpretations of all

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[15] See case studies of Australia and Zambia

[16] SRTM: Shuttle Radar Topography Mission: http://www2.jpl.nasa.gov/srtm/. See also section 2.6.1.

mapping units for various purposes from construction to sewage absorption fields – but no one else followed.

2.5 What do they actually use and where do they get it?

What are their agendas, commitments, doubts, constraints, problems, blockages to use of land resources information? Where is the cadre of experts?

We need to do the research to answer these questions: to compare information needs with information used, timeliness, degree of detail and/or generalisation, accuracy/reliability, comprehension, credibility and value for money; to assess access to information and expertise, maintenance of public datasets, and stability of institutions.

2.5.1 Today's sources of information

For most of the twentieth century, land resources surveyors worked painstakingly over the ground, area-by-area. For each area they drew a map and wrote a report. To the authors, the real output was the report and the map a view into it. But to the users, it was the map that mattered – it was pinned on the wall; the impenetrable report was often lost. Over the last 25 years, advances in computing power have made it possible to work with enormous banks of data - and almost replaced the paper map and report. Survey procedures have been transformed by related advances in remote sensing such as digital elevation models of high precision, an array of satellite-borne instruments that provide global coverage and increasing detail, and airborne geophysics that opens new windows on the world. Slow and costly laboratory analysis may soon be superseded by diagnostic surveillance making use of advances in infra-red spectroscopy. Rigour and confidence have benefitted from the application of advanced statistical methods and measures of uncertainty. And more tangibly from the users' point of view, geographical information systems enable competent professional staff to present and integrate data from different sources. Yet, just as all this is being won, it is being lost as satellites fall and the information is forgotten: digital data are ephemeral, there is no strategy to maintain them and, often, no assumption of responsibility.

The World Wide Web has revolutionised access to information. Some years ago, a survey of members of Parliament in the UK revealed it to be their main source of information. But the internet does not exert the experienced judgement formerly provided by in-house professional staff. It is asking a lot of a busy decision-maker to seek-and-find-and-query technical data through a land resources data system. And they don't. The loss of the professional cadre means not only that less natural resources information is used now than formerly but its quality is unknown - except to specialists whom, in many cases, judge it to be not fit for purpose.

Worldwide, there are now few active soil survey organisations. We have two institutions in the Netherlands to thank for keeping tabs on the available information: David Rossiter (2010) maintains a database of on-line soil survey information and ISRIC–World Soil Information has compiled soil and terrain (SOTER) databases from the extant data for about half the land surface, mostly at scale 1 million or 1:5 million (Engelen and Wen 1995). There are a few archives of original soil survey reports such as WOSSAC[17] and ISRIC (see case studies) but their continuation is precarious.

[17] The World Soil Survey Archive and Catalogue (WOSSAC) incorporates the substantial archive of Hunting Technical services including paper maps and reports, air photos and film, as well as materials from the Land Resources Division and home soil survey organisations, see http://www.wossac.com/

Climatic data are also uneven; there is a dense network of well-equipped recording stations across most of Europe and North America and modest-to-sparse coverage elsewhere. A lot of effort goes into forecasting, which has been revolutionised by real-time satellite data, but global climatic data depend on collations by a few organisations like the Climatic Research Unit (CRU) at the University of East Anglia (Mitchell and Jones 2005) and the German Weather Service (Beck and others 2005, Schneider and others 2008) that do not have access to all the available data. For historical data sets needed to assess climate change, the situation is precarious; data have been accrued by a few interested individuals and, sometimes, maintained in an amazingly amateur fashion – as emerged in the attempt to discredit CRU in the run-up to the recent Copenhagen climate-change conference. Hydrological data are even more patchy and discontinuous. And no two consecutive land use surveys have employed the same criteria (*e.g.* globally JRC 2003 and FAO 2008; for Australia, Barson and others 2000).

By definition, renewable natural resources change over time. Measurement, estimation and prediction of these changes is fundamental to our understanding of processes like land degradation and carbon storage, and essential market-related incentives like carbon, salt and green water credits. But tools are not available to monitoring of these changes by regular field surveys. The best information comes from long-term experiments such as those established more than a hundred years at Rothamsted (since 1843); Grignon (1875) in France; the Morrow Plots, Illinois (1876), Sanborn Field, Missouri (1888), South Dakota (1892) and Auburn, Alabama (1896) in the USA; Halle/Salle (1878), Bad Lauchstadt (1902) and Dikopshof (1904) in Germany; Askov (1894) in Denmark; and for lesser but still significant periods at a few other sites. Very few countries have good soil monitoring studies and they are always under threat in straitened times; otherwise, reliance is placed on proxies and simulation models.

2.6 New activities and advances in knowledge

2.6.1 Digital elevation models

Digital elevation models (DEMs) have supplanted conventional topographic maps for many applications in environmental modelling: the distribution of solar radiation, rainfall patterns and water movement, ecosystems, soil genesis and the mobility of animals are all intimately linked to landform and aspect.

Early DEMs were laboriously constructed from topographic maps. Pioneering development of sideways-looking airborne radar for the *Radambrazil* project, beginning in 1970, produced the first topographic maps of areas perennially obscured by cloud but, apart from a similar and essentially political application in Nigeria (Parry and Trevett 1979), the cost of airborne radar survey meant there were no further orders. Technological breakthroughs enabled synthetic-aperture radar on board the space shuttle Endeavor (February 2000) to deliver a near-global digital elevation model , first released publicly at 90m horizontal and about 1m vertical resolution, now generally available at its full 30m resolution (SRTM 2004, CGIAR-CSI 2004).

Remotely sensed elevation data have shortcomings: there are voids in areas of high relief, deduced stream lines are often wrong, and the surface measured is the top of the vegetation canopy - not the ground surface. Correction is not easy but, once achieved, various useful products can be derived from the DEM:

slope gradient, aspect and curvature, contributing area and wetness index (Gallant 2011) which can then be used to predict soil properties and ecological patterns.

SRTM is already taken for granted and digital elevation data continue to improve along with measurement technology. Airborne LIDAR[18] provides high-precision data (vertical accuracy 20 cm or better, horizontal resolution 1m or better) that can resolve discrete layers of vegetation as well as the ground surface. New global DEMs are being acquired that will replace SRTM in the years ahead; the TANDEM-X satellite radar system will potentially produce global elevations at 2-3 times better resolution and accuracy than SRTM. Higher resolution brings further technical challenges, not least the volume of data; for instance, each 1second-definition DEM product for Australia, say slope gradient, is a 40GB dataset; finer resolutions will be correspondingly bigger.

2.6.2 Predictive ecosystem mapping

Lack of useful information for large areas, combined with the cost, slow progress and uncertain accuracy of conventional surveys, have encouraged the application of predictive models to map site attributes rapidly and cost-effectively. Predictive mapping relies on: 1) a general understanding that ecological differences are controlled by environmental gradients (moisture, energy, nutrients) that are, themselves, determined by topography and 2) the assumption that spatial patterns (of ecosystems, soils and their various attributes) can be predicted by formalising biophysical knowledge into rules that can be applied to existing digital datasets (Zhu & Band 1994). For instance, topo-climatic attributes computed from a DEM may be used to automatically extract topo-climatic classes. It is a short step to derive ecologically predictive landform classes such as wet, gently-sloping toe slopes and bottomlands, dry steep slopes, and so forth; and to infer soil patterns (Zhu & others 2001, McBratney and others 2003).

For mapping 8 million ha of the forested Cariboo region of British Colombia, MacMillan and others (2007) defined the mapping units using local knowledge of site types important for forest management. All available and relevant digital data were registered to a 25m grid (the finest detail that could be supported by the available DEM and equivalent to a map scale between 1:25 000 and 1:50 000). These data included maps of bioclimatic regions and materials depth and texture and, also, automatically generated topographic elements derived from the DEM (slope gradient and curvature, relative landscape position). Rules were drawn up for automatic pattern recognition using a *fuzzy semantic import model* (Burrough 1989, MacMillan 2003): each class was defined as a weighted average of a series of attributes, where attribute values were computed as fuzzy membership functions relating the value of the parameter (*e.g.* slope gradient) with the likelihood of the value matching the concept of the class (*e.g.* steep slopes). Weightings were based on expert knowledge of the survey area and preliminary results were tested against expert knowledge and field examination, and refined or re-defined until an acceptable outcome was achieved. Once approved, the rules were applied to the assembled input data to produce a seamless mosaic of predicted values.

This is classical free survey procedure - except that the surveyor's model of the landscape is written down as formal, numerical rules that can be tested and improved with further knowledge, and the map is drawn by a computer that follows these rules exactly and consistently. Independent assessment found the predictive maps achieved better than the minimum acceptable accuracy of 65 per cent and outperformed mapping by conventional procedures at a fraction of the cost.

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[18] LIDAR: Light Detection and Ranging is an optical remote sensing technology that can measure the distance to, or other properties of, targets by illuminating the target with laser light and analyzing the backscattered light.

2.6.3 Normalised Difference Vegetation Index (NDVI) applications

Natural resources surveyors have always made good use of new technology that was originally developed for other purposes. The title of a paper in *Advances in Space Science:* 'The exciting and totally unexpected success of AVHRR in applications for which it was never intended' (Cracknell 2001) says it all. AVHRR is the Advanced Very High Resolution Radiometer mounted on NAASA meteorological satellites – actually very low resolution, even compared with the Landsat satellite data already being collected at the time, but its large field of vision and daily global coverage made it ideal for global monitoring. By happy chance, the ratio of red to near-infrared radiation measured by the radiometer (NDVI) is a good indicator of vegetation dynamics. The *Global Inventory Modeling and Mapping Studies* (GIMMS) dataset of corrected monthly NDVI values at 8km resolution, extending back to 1961 (Pinzon and others 2007), was used for the *Global assessment of land degradation and improvement* (UNEP 2007, Bai and others 2008). The 25-year trends of NDVI, translated in terms of net primary productivity (NPP) and taken as a proxy for the condition of the land, revealed a global picture (Figure 4) quite different from received wisdom. The results were met by the 'experts' with the first two stages of the usual public reaction to a new truth; the third stage has not materialised because no country or major organisation took ownership of the analysis.[19]

More recent satellite-borne sensors now produce more detailed and more direct measures of NPP, *e.g*. MODIS imagery provides a continuous NPP dataset derived from the fraction of absorbed photosynthetically- active radiation, which is a more direct physical measurement of ecological processes than NDVI, acquired every three days with a spatial resolution of 250-1000m (Running and others 2004) but these newer sensors cannot match the now thirty years of consistent, corrected data represented by the GIMMS dataset.

2.6.4 Airborne geophysics

Airborne geophysics was developed for minerals exploration. *Airborne radiometrics* measures the intensity of natural γ-radiation emitted by potassium (K), uranium (U) and thorium (Th) using a sensor mounted on a low-flying aircraft. Gamma-rays are absorbed by soil and water so the signal reflects only the composition of the upper 35cm of soil, less if the soil is wet. Results may be reported as individual-element counts or as ternary maps made by assigning colours to each element, portraying higher concentrations as brighter colours. Biophysical applications depend on subtle interpretation: radio-elements occur in different concentrations in different rocks – highest in acid igneous rocks, absent or low in basic igneous; they also behave differently under soil–forming processes - K is readily weathered and leached but accumulates in illite clays and may be adsorbed by other clay minerals; in contrast U and Th are associated with resistant minerals like zircon so they accumulate in strongly weathered soils. From Australian experience, combination of radiometrics with landforms analysis yields invaluable insight into

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[19] The original proposal to FAO, the executing agency of the GEF/UNEP *Land degradation in drylands* project was to train local staff in a network of regional centres to undertake the analysis of NDVI satellite imagery, so as to build local capacity and, importantly, ownership of the results - in the knowledge that the NDVI dataset will become more-and-more valuable as the period of consistent NDVI data lengthens, better measurements of net primary productivity come on stream, and there are more layers of information to uncover (de Jong and others 2011, Bai and others 2013) But FAO opted for the quicker, cheaper option of in-house analysis by the project proponents ISRIC-World Soil Information. When it transpired that drylands were not the main problem, FAO proceeded to bury the inconvenient information in a series of parallel and scientifically indefensible analyses.

soil parent materials (Cook and others 1996, Wilford and others 1997, 2001) which has recently been translated to very different landscapes in NW Canada (MacMillan and others 2008, Dent and others 2013).

Salinity and fresh water are two sides of the same coin and most conveniently measured by electrical conductivity. They can be mapped in three dimensions to more than 100m below ground by *airborne electromagnetics* (AEM). In dry lands, salt is held as briny pore fluid in the regolith.[20] The survey aircraft generates an electromagnetic field that penetrates the ground, inducing an electric current in conductive materials like brine; in turn, the current induces a secondary electromagnetic field that is detected by a receiver towed behind the aircraft. The signals are translated into a three-dimensional map of conductivity that may be calibrated against measurements of salinity in bores. *Airborne magnetics* reveals geological structure including magnetic gravels that may serve as conduits for groundwater flow, dykes that may be barriers to flow and faults that may act either way. The combined information enables rapid mapping of salinity, groundwater flow systems and water resources and assessment of the outcomes of management interventions at a cost of about one $US/ha (Dent and others 1999, Dent 2007).

2.6.5 Infra-red spectroscopy

Laboratory analysis has an equivocal reputation in resource assessment; it represents exactitude and scientific respectability, but it is hard to detect the contribution of these data to actual development. Soil and plant testing services played an important role in ‘scientific agriculture’ in industrialised countries after the end of the Second World War; they were popular with farmers - especially when provided free of charge by national agricultural advisory services. Comparable agricultural development in the tropics will need tens of thousands of field trials to develop improved crop and soil management practices, supported by millions of soil and plant analyses, but national soil and plant testing laboratories are closing down.

Increasing demands for quality control from export markets, implementation of payments for environmental services, as well as the need (never realised) for rigorous environmental baselines and monitoring to support policy formulation were never going to be met by conventional laboratory methods that require costly equipment and costly and rare skilled analysts. Recent advances in infra-red spectroscopy[21] calibrated by benchmark data from conventional analyses (Shepherd &Walsh 2007 Terhoeven-Urselmans 2008) offer cost-effective and reproducible measurements of multiple constituents in a wide range of materials - in seconds and with no sample preparation. The cost is a few cents or dollars per sample compared with hundreds of dollars. More importantly, there is no need for costly laboratory facilities and exacting staff training. Applications include soil analysis (of carbon, organic matter fractions, plant nutrients, salinity and sodicity, heavy metals, particle size distribution, clay mineralogy, and some physical and engineering characteristics); soil and water quality assessment; monitoring schemes for environmental payments; seed and crop tissue screening, crop and livestock health and quality testing Pending development of dependable field instruments, these services can be provided by decentralised or mobile IR spectroscopy units. The ability to acquire a high-density of measurements of the quality of resources and materials, linked with case definition for specific problems, offers a step change in agricultural and environmental management - from detailed measurements of a few samples, extrapolation of results and reliance on expert opinion, to a focus on interpretation of measurements and interpolation of results.

[20] The uppermost, weathered part of the solid Earth, above fresh rock and including soils

[21] Infrared spectroscopy taken in the broad sense but, in particular, diffuse reflectance spectroscopy within the near infrared and mid infrared wavelength range

2.6.6 Land resource information systems

If spatial data are made available in digital form with no or liberal use restrictions, anyone can use them, perhaps in novel ways (Fisher 2003) and, nowadays, more and more spatial information is deployed within computer-based geographic information systems (GIS). Added to an effective planning department and with its own dedicated staff, GIS can quickly combine various layers of data, for instance land use, land ownership, planning units and infrastructure to reveal new information and depict this information in a way that decision-makers can grasp.

An early example is the Texas Natural Resources Information System (TNRIS), established in 1968 and operated by the Texas Water Development Board (http://www.tnris.org/), It provides a common access point for Texas Natural Resources data, census data, digital and paper maps, and information about datasets collected by state agencies and other organizations. The first national computerised natural resources information system was the Canada Land Data System, and CanSIS the first national soil information system - fully operational in the 1970s and a model for many that have followed (McDonald and Brklacich 1992, Agriculture Canada 2011). At the outset, it was championed by senior management in Agriculture Canada which ensured that and technical and financial resources were enough for the scientific team and technical staff to make it work. CanSIS now serves policy- makers in Agriculture and AgriFood Canada, land use planners, natural resources managers in agriculture, forestry, ecology, parks and recreation, water, and environmental protection; farmers and growers; agronomists; engineers; and researchers. A wide range of information is to be found at a common web site (http://sis.agr.gc.ca/cansis/), national-scale web maps are easily accessible, and a guide to more detailed printed maps and reports information (and human assistance) are provided.

By contrast, the present state of the Australian Soil Resources Information System (ASRIS) demonstrates how hard it is to meet the needs and aspirations of land resources scientists and decision-makers if the necessary human and financial resources are not made available. Without effective professional support and if the relevant data are not in the system, land information systems cannot deliver the promised information at the touch of the key. There are two issues:

- GIS is hard to use unless you are familiar with it. Unlike Google Earth, it's not easy to work through different levels of scale and detail - so the systems deliver best if they are centrally housed in key institutions with good staff and facilities;
- Data for different attributes and scales are rarely compatible, being derived from various sources and collected at different times and for different purposes.

There is a comparably mixed picture in developing countries. In Sri Lanka, even with the technology available off-the-shelf 30 years ago, if the data were in the GIS, policy planning questions of the day could be answered on the spot and this contributed to better-informed decision making (Jayasinghe and Ridgway 1985). And one data set can be a useful check on another; in compiling soil and terrain data for Central Africa on the new SRTM topographic base (ISRIC 2008), corrections of sometimes hundreds of km were made to the positions of whole river systems, and their associated soil patterns. In recent decades, computer-based land resource information systems have been the only growth area in natural resources information - in vogue as a substitute for human experts. Even the smallest countries have them, usually supported by outside money and technical expertise (*e.g.* Niue, Box 6).

In the Caribbean, the Global Environment Facility (GEF) has funded sustainable land management (SLM) projects in Barbados, Dominica, Grenada, St. Kitts-Nevis, St. Lucia, and St. Vincent and the Grenadines, all with the aim of mitigating land degradation and maintaining ecological integrity and productivity by capacity-building in government, civil society and the private sector - focusing on knowledge management and including a computerised Land Resources Information System.

Box 6: Developing a land information system in Niue

Land degradation is a big concern in the Pacific island of Niue. It is increasing as a consequence of ploughing, shifting cultivation with much reduced fallow periods and reliance on synthetic fertilizers/herbicides, and extensive land clearance for export cropping of taro. 'In addition, there is a lack of coordination of available land information data, reports and their integration as a resource planning tool to address optimum land functionality with due consideration to ecosystem integrity' (UNDP undated).

UNDP recognised the need for better dissemination of such information - but in a user-friendly way that facilitates good land-use decisions. It has supported a five-year (2006-2011) sustainable land management (SLM) project in Niue which, amongst other things, has developed a Land Information System to provide a framework for managing land information data.

A desk study of land information systems for the Pacific Islands Forum Secretariat (McIntyre 2008) notes some of the common shortcomings that the appearance of information technology cannot rectify:

> *'There are significant gaps in adequate and suitably characterised environment and development information in the Pacific and small-island developing states. Poor knowledge of much of the region's ecological physical and biophysical systems, as well as the socio-economic drivers for change, is a serious constraint to sustainable development. Effective land use, economic and environmental decision-making requires credible data verified or enhanced by local experience, consistent information baselines, and indicators that are systematically upgraded. As well, there are needs for systems to monitor relationships and to disseminate the outcomes of decisions to communities. Information on the current population trends, the status of endangered species and characterisation of ecosystems is particularly lacking. There are serious gaps in geographic data…'*

A worst-case scenario is illustrated by a fisheries information system set up in an East African country to inform the Minister and heads of departments dealing with policy and specific investment decisions, and to circumvent subjective judgement and personal agendas. Scientific staff have gained experience in handling computerised fisheries data and some new knowledge has been created but the system has failed in its stated aim. There have been clashes of interest with other departments that sought to avoid the information; the fishermen wanted to go their own way regardless of any 'scientific' priorities; and almost all decisions by senior officials and committees are taken without regard to the information provided by the system – with continued negative outcomes for East African fisheries (Anon 2002).

'O brave new world.'

Brave new world. Aldous Huxley 1932

Chapter 3

CONCLUSIONS

'Ye shall no more give the people straw to make brick, as heretofore: let them go and gather straw for themselves.'

Exodus 5

But the Pharoah demanded the same daily output of bricks.

3.1 The policy context

Land, water, climate change, sustainable and unsustainable agriculture, roles and responsibilities, atrophy of land resources information

Each generation regards the land according to its own lights. The first settlers cleared the natural vegetation to replace it with something more familiar and, they believed, more productive. And the land was changed profoundly. Man-made landscapes geared to produce food and raw materials evolved under generations of management - sometimes successfully, sometimes not. Only recently have we appreciated the range of ecosystem services that are also provided by the land and which underpin productive uses and the urban communities that now make up half of mankind.

During the Golden Age, demand for land resources information came mainly from governments and was satisfied by government agencies and private companies. But the loads governments took upon themselves in attempting to direct, administer and implement the use of every field and hillside exceeded the both the supply of information and their own abilities to make use of it (Dalal-Clayton and Dent 2001). In the Age of Uncertainty, governments abdicated responsibility for land use and management and turned to markets to deliver their aims.

The world has never been so rich or well fed. But both industrialised agriculture and unsupported subsistence farming are driving land degradation and climate change – and the costs are passed on to future generations. Market failure and policy failure have built up an overdraft that will be hard to repay. The challenge for society is to devise sustainable ways of managing land resources that will deliver almost twice today's production by 2050. This means 'high farming' - a combination of *conservation agriculture* (no-till, crop rotation with perennial legumes, mulching with crop residues, and substantial applications of manure as well as mineral fertilizers) and *precision agriculture* that adapts farm operations to the diversity of the landscape, taking advantage of natural variation rather than ignoring it (UNEP 2007, Kassam and others 2009). But high farming demands a high level of knowledge, more-detailed land resources information than has yet been systematically gathered, and sustained policy and institutional support that provides incentives for change. Sustainable management of forests, rangelands, wetlands and barrens is just as critical; we depend on them for delivery of environmental services.

The need to factor good land resources information into development policy, planning and management seems obvious and logical. Yet, as we have noted, this appears to be happening less and less. Demand for land resources information has waned, even in countries like Australia and South Africa that depend overwhelmingly on their natural resources and, at the same time, are vulnerable to climate change. Institutions tasked with collecting, maintaining and interpreting the information have been dismembered. Fundamental data are dispersed, fragmented and, in many cases, more than thirty years old; most databases were created in response to yesterday's issues; they are incomplete and sometimes, maintained in an amazingly amateur way without adequate funding or any credible strategy for continuation and development; data sets of related fields are not linked. The erosion of specialist skills within natural resources agencies and universities has created capacity gaps that will be hard to fill. Without the cadre of experts, such data as we have are drifting away from the status of live information that is a part of current practice and case law into the status of fragmentary historical documents.

3.2 How to put things right

Rebuilding commitment, the knowledge base, and capacity

How to put things right? Shouting at decision-makers and telling them that they are doing a bad job or getting it wrong doesn't help. In the absence of a firm *pull* in the shape of demand for natural resources information, *pushy* agendas trying from outside to introduce different ways of doing things is a difficult and, usually, fruitless pursuit – for which there are many exemplars. Far better to secure a *pull* by dialogue with decision-makers, seeking to understand their needs and concerns, and explaining how our own ideas or solutions might help.

Without returning to command-and-control, strong arguments have been advanced for formal land resources policies and framework legislation. For instance, the European Commission Soil Thematic Strategy (2006a), which received common assent, called for a comprehensive approach to *preserve soil functions* by action on four fronts: awareness raising, research, integration of soil protection with other policies, and legislation. The first three have been implemented to some extent (under the EU Common Agricultural Policy payments are withheld if minimum standards of husbandry are not met - but these standards fall well short of sustainability): the proposed Soils Directive (EC2006b) was blocked in the Council of Ministers - the UK was one of four governments opposed.

Payments for environmental services may be seen as a market-related alternative. Carbon trading was initiated some years ago under the Kyoto Protocol but trading in carbon fixation through forestry and land use change is small-scale and only the Alberta market deals in soil carbon; salt trading has been implemented in the Murray-Darling Basin in Australia; green water credits has been researched in a few countries (Dent and Kauffman 2007) but not yet implemented. All such mechanisms require reliable, up-to-date information on the status and change of specific land resources - information that is hard to get and hard to judge. And yet, the information itself has few champions. Out of 283 paragraphs summarising the outcomes of the 2012 *Rio+20 UN Conference on Sustainable Development*, fundamental land resources information received a glancing reference in just three.

The facts don't speak for themselves. Someone has to speak up for them. Time and time again in the case studies, we have seen how progress can be accelerated by working with influential people or organisations that are in a position to champion the cause: the Minister for Mahaweli Development, Gamini Dissanayaka, in Sri Lanka; Minister Wilson Tuckey championing airborne geophysical surveys and the National Action Plan for Salinity and Water Quality in Australia; Premier Wen Jiabao persuading provincial administrations to fund the multi-objective geochemical survey in China... However, our champions should be armed with a compelling analysis of alternative natural resources strategies, comparable with the Stern Report (Stern 2006, Hamilton Group 2009), and that requires detailed and indisputable land resources information.

Sustainable development depends on rebuilding the knowledge that allows progress from denial of land resources issues, to recognition, to accepting ownership; and then provides a foundation for effective decisions. This review is but a start. It has been based on a few case studies, an internet search and information provided by colleagues in the field. It is, therefore, a partial examination of the state-of-play -

although we believe it indicates fairly the trends across the world. Three policy tracks have to be followed to rebuild knowledge of the land:

- Awareness, education, training and investment to maintain the science;
- Research to understand land resources problems and processes and to find solutions;
- Community and industry participation to share the load once ownership has been accepted.

For individual governments, industries or companies to take action, signposts are needed: first to determine the dimensions of policy and management issues; then to assess the adequacy of existing information and specify exactly what new and better information is required. In the appendix, we have sketched a diagnostic procedure for establishing the state of knowledge and specifying exactly what else is needed – generally, this is not what the sellers have to offer.

Any way out of the woods will require better, more detailed, more publicly-accessible land resources information than we have seen heretofore. This cannot be turned on like a tap; land literacy[22] is learned only by rigorous training and long experience in the field. Across the western world, most of the cadre of professionals is pensioned off and, with the evaporation of demand, universities and colleges no longer offer training in land resources survey and land use planning. There is urgent need for a career structure, education and training for a new cadre of experts.

What will it cost and how long will it take to rebuild the necessary commitment to land resources, the knowledge base, and capacity for effective action? For the UK, still, it may not be necessary to start all over again from scratch. Once government and industry know what they need, roles may be assigned to existing institutions with related expertise that can appoint natural resources liaison officers to broker relevant, reliable information and specify what further information may be required. As we have already argued, once there is demand, supply follows. For the UK, the ongoing cost will be no more than is spent today by Premier League football club, or middling university. For the western world, the time horizon is a generation: the Chinese and Brazilians are already well on the way.

'What is the price of Experience do men buy it for a song
Or wisdom for a dance in the street?
No it is bought with the price
Of all that a man hath, his home, his wife, his children.
Wisdom is sold in the desolate market place where none comes to buy
And in the withered field where the farmer ploughs for bread, in vain.'

Vala. William Blake 1820

[22] Land literacy is the ability to read the health of soils and landscape.

CASE STUDIES

AFRICA

Africa faces great challenges. Agriculture supports 80 per cent of the people and contributes 20-50 per cent of GDP but, in most places, crop yields remain stubbornly low. The only consistent policy has been serial target setting. Policy failure has led to erosion of soils, capital assets and professional capacity. North Africa is in the throes of political revolution. In Sub-Saharan Africa, 280 millions go hungry - more people than ever. Policy statements proclaim: ‘The African Green Revolution will be driven by smallholder agriculture moving to higher-value production’ (NEPAD 2010, Montpellier Panel 2010) and call for ‘coordinated, integrated development’, ‘less price volatility’, ‘public-private partnership’, ‘credit, insurance and subsidy schemes...’ No one admits to lack of human capital but the people are not in place to match the aspirations - and decades of development assistance signally failed to build this capital. Our correspondents identify various underlying reasons why current governance is failing:

- Lack of political commitment to sustainability (at all levels of government) and inability or unwillingness to enforce competent laws
- Federal systems of government assign responsibilities and duties to the state and local authorities without providing the capacity or adequate funding. So devolved authorities resort to exploitation of natural resources; poverty forces local communities to follow suit.
- Appointment or election of decision-makers and planners on grounds of politics rather than competency
- Corruption and mismanagement of finances by bloated legislatures, executive and administrative bodies
- Weak capacity to apply scientific information to policy-making, in particular to issues of sustainability
- Lack of coordination amongst stakeholders
- Lack of land use plans and the land resources information needed to make them, land use, land capability, national databases and systems to monitor land degradation, and lack of quantitative environmental indicators related to land and water.

To be fair, such analysis is not confined to Africa.

South Africa

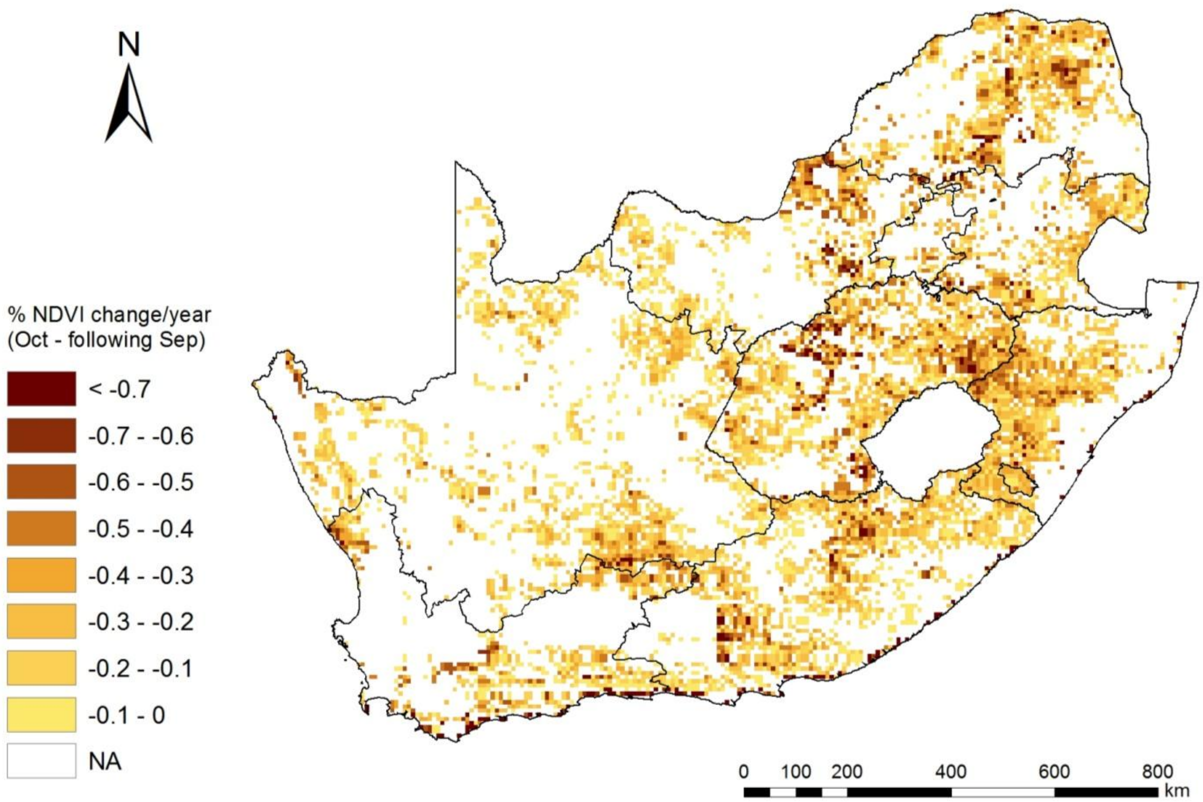
Area 470 693 square miles (1 219 090 sq. km), Population 48 577 000

With Penny Urquart

Context

South Africa is a dry country with all the usual social and economic development issues. Land resources are stretched to meet the aspirations of the people; climate change is compounding already critical issues of water scarcity and land degradation. Taking a negative trend of net primary productivity (NPP) as a proxy indicator of land degradation (Figure 5), NPP decreased over the period 1981-2006 against a population increase of 50 per cent (30 million to 45 million). Twenty nine per cent of the degrading area is cropland (41 per cent of the cultivated area) 33 per cent is forest and 37 per cent rangeland. Overall, these areas suffered an average NPP loss of 29kgC/ha/yr.

Figure 5: South Africa – Proxy assessment of land degradation 1981-2006 (negative RUE-adjusted NDVI trend after Bai and Dent 2007)



About 17 million people (38 per cent of the population) live in the degrading areas. Degradation is somewhat over-represented in communal areas but not overwhelmingly; there is no obvious relationship with soil or terrain and only weak correlation with aridity. NPP increased across one third of the country; most of these areas are rangeland in the dry west.

Natural resources issues

There have been some advances in the collection and presentation of land resources information but there are still critical gaps, and accessibility of extant information leaves much to be desired. Skills and capacity are wanting in the use of information in decision-making – particularly in collaborative use of information by different spheres of government and, most particularly, where there are overlapping jurisdictions; provincial and municipal planning systems cannot handle regional issues. There are a few good provincial planning departments, *e.g.* the Western Cape, but many municipalities struggle and simply do not have appropriate skills. Politics and vested interests impede better usage of the data. Impending legislation referred to as 'South Africa's Orwellian Information Bill', although aimed at state security issues, includes in the definition of security: 'protection against exposure of economic, scientific and technical secrets vital to the Republic' – which might easily be used to block development proposals and remotely sensed information.

Institutional needs for land resources information

Key decisions on rural development are made by the National Planning Commission, within the Presidency, and the Department of Rural Development and Land Reform (RDLR). The Rural Disaster Mitigation Service is conspicuous within the RDLR although decisions made by the Department of Economic Development and the Treasury may have a greater impact on key rural development decisions. Land resources information is also needed and used at the national and provincial levels by the departments of Agriculture Forestry and Fisheries, Energy, Environmental Affairs, Mineral Resources, Tourism, and Water Affairs; by related institutions in the municipalities; by academic and research institutes; industry (*e.g.* mining); farmers and other natural resource users; NGOs and civil society. Their needs are many and various.

Information providers

Topography and geology

The Council for Geoscience, successor to the Geological Survey of South Africa, is responsible for mapping the country. Topographic mapping is good and up-to-date. Basic geological mapping is complete at scale 1:250 000 but incomplete at 1:50 000 across many areas where it is needed. Most data are available digitally but the big increase in the prices charged for data raises concerns about accessibility.

Biodiversity

Responsibility rests with the Department of Environmental Affairs, together with the SA National Biodiversity Institute (SANBI) which has legal obligation to manage and disseminate biodiversity information. SANBI is the fourth biggest contributor to the inter-governmental Global Biodiversity Facility, serving more than 14 million primary biodiversity records, the Relist status of over 20 000 plant species, more than 30 conservation plans, and many other data sets.

Biodiversity data are collected or collated for planning by all tiers of government, *e.g.* provincial conservation agencies and municipalities, by NGOs and academic research units. SANBI's Biodiversity Advisor (http://biodiversityadvisor.sanbi.org) provides access to all available data, reports, user guides and tools such as the Land-Use Decision Support Tool developed for use in environmental impact assessments. It is unclear whether this or other tools are, in fact, used by various tiers of government.

Land use and land degradation

Responsibility for collection of data on land use and land degradation was always the responsibility of resource conservation technicians and agricultural extension services. The 1991 National Land Degradation study noted the need to revive the agricultural statistical service to provide reliable data for planning in both commercial and communal farming areas – so the lack of such data was already a serious problem more than a decade ago.

Hoffman and others (1999) summarised the severity, extent and rates of different types of land degradation within the 367 magisterial districts based on qualitative assessments by natural resources conservation officers; more recently, degraded lands were mapped as part of the National Land Cover map using expert interpretation of 1995-6 Landsat imagery (Fairbanks and others 2000). Recent comprehensive assessments have been driven by international commitments, *e.g.* under the SA National Action Programs under UNCCD, and by the Agricultural Research Council Institute for Soil, Climate and Water as part of the FAO LADA project in support of the DAFF Soil Protection Strategy. Wessels & others 2007 used AVHRR NDVI data at 1km^2 for 1985-2003 and modelled NPP at 8km^2 for 1981-2000 to estimate vegetation production in terms of rain-use efficiency and residual trends (the difference between observed ∑NDVI observed and ∑NDVI predicted by its relationship with rainfall).

The former *homelands,* now called communal lands are a major concern (Hoffman and Todd 2000, Hoffman and Ashwell 2001). Their big human and livestock populations are accompanied, overgrazing, soil erosion, excessive wood harvesting and loss of palatable pasture species (Shackleton and others 2001) - problems attributed to a combination of poverty and failure of regulation (Scholes and Biggs 2004) arising from both current social and economic changes and a legacy from the previous apartheid regime (Dean and others 1996, Fox and Rowntree 2001, McCusker and Ramdzuli 2007). There is concern that current land redistribution programs might expose productive land to the same drivers of degradation: the lessons of neighbouring Zimbabwe are very close to home . However, degradation also occurs on commercially farmed land; Bai and Dent (2007), reviewing the 25-year trends of rainfall-adjusted NDVI, found that degradation is somewhat over-represented in communal areas, but not overwhelmingly.

Water resources

The Department of Water Affairs, Directorate of Water Resources Information Management, is responsible for managing data needed for strategic and development planning of water resources, as well as international agreements. In 2005, the Department established a governance institution to coordinate and share resources and information across water management institutions, working towards common standards for data acquisition and management and quality assurance. Data are, or have been, collected under assorted national monitoring programs and through environmental impact assessments. In addition, catchment management authorities and water boards are responsible for monitoring status and trends at finer resolution, *e.g.* regional or catchment monitoring programs, water use licensing, and assessment of compliance with licence conditions.

On the whole, the hydrological database is considered to be in good order, hydrological stations are maintained and the data are available on the website http://www.dwa.gov.za/hydrology. According to the 2010-11 Annual Report (Dept Water Affairs 2011), annual targets for hydrology and geo-hydrology monitoring were exceeded because of the response to drought and flood in the Eastern and Western Cape.

On the other hand, there is consensus that South Africa's water quality is fast deteriorating while the scientific and engineering capacity to counter the problems is shrinking.

Use of land resource information in policy-making, planning and development decisions

The 2006 State of the Environment (SoE) Report identified accessible and consistent information as one of four key areas requiring response and improvement:

> *'There are serious gaps in environmental data that seriously hamper our efforts to make better policy decisions. The current SoE report had to rely on inventory data for greenhouse gases that are more than 10 years out of date. Critical indicators for which we have no adequate data include current land cover, fine-scale spatial information on habitat degradation, aspects of water quality, air quality and carbon emissions. We also do not have reliable data on genetically modified organisms, human vulnerability, or groundwater use and recharge, and limited knowledge on some aspects of biodiversity. There is further a need for a consolidated and consistent monitoring and evaluation system… Monitoring is often not carried out at regular intervals and, in some cases, is so sparse that meaningful interpretation over large spatial scales cannot be made.'*

The National Framework for Sustainable Development, gazetted in 2008, highlighted the same constraints of land resources information. Yet, in June 2011, the Overview of the first Diagnostic Report by the National Planning Commission, identifying the main challenges confronting the country, makes no mention of the data challenge. This may indicate the perceived importance of good baseline data on land resources.

There is no doubt that the country faces pressing land resources problems, not least concerning water resources and land degradation. The scientific and engineering capacity to counter these threats is shrinking – pensioned off or, in some cases, whistle blowers have been fired. There are two critical and related issues to which answers cannot be given without specific research: the question of what information is actually used, and the perception of how important this information is. There will be many bureaucrats and politicians who appreciate the importance of land resources information and would make use of more-accessible information - but there are many more who do not see sustainability and evidence-based decision making as imperatives.

Zambia
Area 290 586 square miles (752 614 sq. km), Population 12.5 million

Context

More than half of Zambia has mean annual rainfall between 800 and 1400mm and is classified as medium-to-high potential for agriculture, but only 3 per cent (about 1.4million ha) is so used (CSO 1996). Of the population of 12.5 million (CSO 2010), 850 000 are farmers; 75 per cent of them smallholders with an average holding of less than 5ha, 17 per cent emergent commercial farmers with 2-20ha, and 8 per cent large commercial farmers working more than 20ha. Agriculture supports 67 per cent of the labour force and contributes 20 per cent of GDP - the lion's share comings from the mining industry which is now in Chinese hands.

Land resources surveys

<u>Soil survey</u> (from Dalal-Clayton & Dent 2001 and Sokotela 2012)

Trapnell's ground-breaking surveys of Northern Rhodesia (1937, 1943, 1949) were well-thumbed by a generation of Agricultural Officers but technical follow-up was limited to the appointment, in 1954, of one soil surveyor based at the Department Agriculture's Mount Makalu Research Station. Ten years later, the Government of newly independent Zambia requested international assistance. This was the high noon of land resources surveys; FAO expert, Hugh Brammer, proposed a national soil survey unit and NORAD agreed to pay for expatriate surveyors, who began to arrive in 1973; and the UK Land Resources Division undertook an extensive land systems survey in the north of the country over several years (Mansfield and others 1975/6).From 1977, NORAD funded the Zambia Soil Survey Unit (SSU).

During the NORAD years, the SSU became one of the most active survey organisations in Africa - securely funded, well equipped and able to undertake an extensive field program; and several Zambian staff trained overseas. For five years, development projects kept the Unit busy with *ad hoc* surveys but a further extension to 1987 prioritised systematic surveys at scales 1: 100 000 and 1:250 000, and a national soil map at scale 1:1million (eventually completed in 1991). It was never clear who requested national mapping or who would use it; there was no attempt to assess national or local requirements. The professional staff themselves ran the show. As a consequence, much of the substantial output was highly technical and remained unused; for instance, a land evaluation system following the latest FAO guidelines was eschewed by the planners - who continued to use the familiar Land Capability Classification.

The agreement with NORAD specified a Zambian contribution increasing throughout the life of the project but this never materialised. When NORAD finally withdrew, in 1991, SSU reverted to its line ministry with an impressive mandate but without the necessary resources. Activity depended on sporadic commercial funds: defining fertilizer and management requirements of the major soils through trials on research stations, collaborative work with other government agencies such as the Zambia Wildlife Authority that were able to attract funding, and *ad hoc* surveys for commercial farmers. Demoralised staff left; the nominal complement was reduced to five in the 1990s and three by 2003.

Transfer of the SSU to the Zambia Agricultural Research Institute in 2004-5 heralded a renaissance. Since 2007, its work has included district mapping (as and when District authorities have interest and can fund it); theme-based research and services covering climate change (much in demand), soil conservation, fertilizer use and recommendations, soil testing, and response to requests for information (it now receives

200-300 queries per year for location-specific soils information and 5-10 requests for information concerning large areas). Since 2005, at the request of the Vice-President's Office, the SSU has been conducting soil surveys and land evaluation of farm blocks – one per province (between 15 000 and 100 000 ha) to resettle people from areas vulnerable to flood or drought. The Unit now has a complement of 30 (15 professionals) and has re-opened regional offices in Central, Lusaka and Copper Belt provinces.

The Ministry of Agriculture continues to provide an Agricultural Extension Service and operates a Technical Services Branch which undertakes some land use planning, farm demarcation, on-farm dam design, and collaborates with the Office of the Vice President on resettlement planning connected with disaster management.

There is a close parallel with the Dutch-supported Soil Survey of Kenya. The Dutch also completed the *Exploratory Soil Map of Kenya* at scale 1:1million (Sombroek and others 1982) and a fair coverage of systematic surveys. The dip in capacity and activity after the end of overseas funding was mitigated by a continuing link with the Kenya Agricultural Research Institute (KARI), one of the most effective agricultural research organisations in Africa, which has maintained a national field and laboratory capability. However, it is hard to ascertain any use of systematic soils and land evaluation data in land use planning; private investors call the shots when it comes to development (Jonathan Davies, personal communication); and KARI is hard put to keep its best staff against the lure of the private sector and prestigious international or overseas institutions.

Geological survey

In contrast to land use, forests, and soil survey, geological surveys worldwide remain fully functional, well-equipped and resourced - certainly in countries where mining and oil extraction contributes significantly to the economy and government income. In Zambia, the Geological Survey Department was established in 1952 (as the Geological Survey of Northern Rhodesia) with the primary task of mapping and data compilation, complementing rather than overlapping the interests of prospecting and mining companies. This relationship still holds. Although the Department has diversified to include engineering geology, geotechnical investigation and site surveys, it still undertakes systematic regional mapping: 58 per cent of the country has been mapped with 123 quarter-degree sheet areas at scale 1:100 000, six at scale 1:250 000, and national map at scale 1:1million (Zambia Geosurvey 2011).

SOUTH AND EAST ASIA

China

Area 3 700 593 sq miles (9 584 492 sq.km), Population 1 340 000 000 (2010 census)

With Zhanguo Bai and Yunjin Wu

Context

China holds 22 per cent of the world's population but only 7.2 per cent of the world's arable land. Food security has always been precarious and now, as the world's second largest and fastest-growing economy, China makes enormous demands on its natural resources. Over the last 10 years, 6 per cent of highly productive land has been lost to urban development and infrastructure, and a gap is opening up between real and expected, or required, production. Even the offshore investment in land, notably in Africa, can have only a marginal impact so sustainable management of the homeland is essential to meet the needs and aspirations of its people.

Strategic information issues include loss of or conversion of arable, land degradation, water use and water resources protection, fertilizer-use, pollution of land and water resources, carbon stocks and carbon-fixing potential, and ever-present geological hazards. China continues to invest strongly in state-of-the-art land resources information, fostering strong institutions and a cadre of tens of thousands of well-trained professionals.

Land resources are administered by a powerful central bureaucracy. The Ministry of Land Resources (MLR) and its provincial and county offices make strategic plans for land use (as farmland, urban, construction, transport and communications *etc*.) which are submitted to the State Council for scrutiny and approval. There are sequential five-year plans for mitigation of geo-hazards, geological exploration and farmland, and land use planning has been strengthened by amendment to the national plan: *Outline of the National Overall Plan of Land Use (2006-2020).* Provincial-level land use planning is under way on a trial basis in some provinces including Guangdong and Liaoning. Further, MLR supervises land use and investigates serious violations of regulations such as unauthorised land use and illegal occupation of primary farmland.

Land-use policy preferentially guarantees state key projects and projects related to people's wellbeing, such as housing and maintenance of farmland for food security. Land use policy includes moving urban and industrial development to the deserts; and enforcement of land zoning goes as far as closure of wells. At the same time, farmers are subsidised according to evaluation of their land, which requires detailed soil survey information. Assignment of land for industrial development is increasingly by public calls for expressions of interest, competitive bidding and auction.

Land resources status and trends

<u>Land use change</u>

To ensure food security, China tries to maintain at least 120 million ha of arable land. Figures for 2007 were (in millions of ha) arable amounted to 121.7, gardens 11.8, forest 236.1, pasture 261.9 and other agricultural uses 25.5; urban and industrial uses 26.7, transport and communications 2.5, water conservancy facilities 36.3; the rest was categorised as unused (MLR 2007). Rates of change are hard to assess because of changing definitions but, over the two years 2006-7 (before the recent economic slowdown), arable and gardens shrank by 0.03 and 0.04 per cent, respectively; forest and pasture by 0.002 and 0.03 per cent; whereas the urban/industrial area increased by 1.11 per cent, transport and communications by 2.05 per cent and water conservation facilities by 0.37 per cent. The net reduction of arable (40 700ha) was only a tenth of the previous year's loss; the total built over (188 300ha) was one quarter less than in the previous year; land destroyed by natural hazards (17 900ha) was half the previous year; while 25 400ha was turned over to ecological preservation. Losses amounted to 236 500ha but, during the same period, 195 800ha was added by land upgrading and reclamation - more than the area of cultivated land taken over for construction.

Slowdown in the loss of farmland may be attributed to enhanced protection and a brake on new construction through the tax system, establishment of a system of evaluation and stronger management of for reclamation schemes, and the establishment of 116 farmland-protection demonstration areas. At the same time, there is a flight from the land. China's rural population could fall from its present 300 million to 280 million by 2020 and a recent survey by the Institute of Geographic Sciences and Natural Resources Research (Liu and others 2009) indicates that some 7.6 million ha lie idle; one quarter to one-third of the land in traditional agricultural regions is abandoned.

Geo-hazards

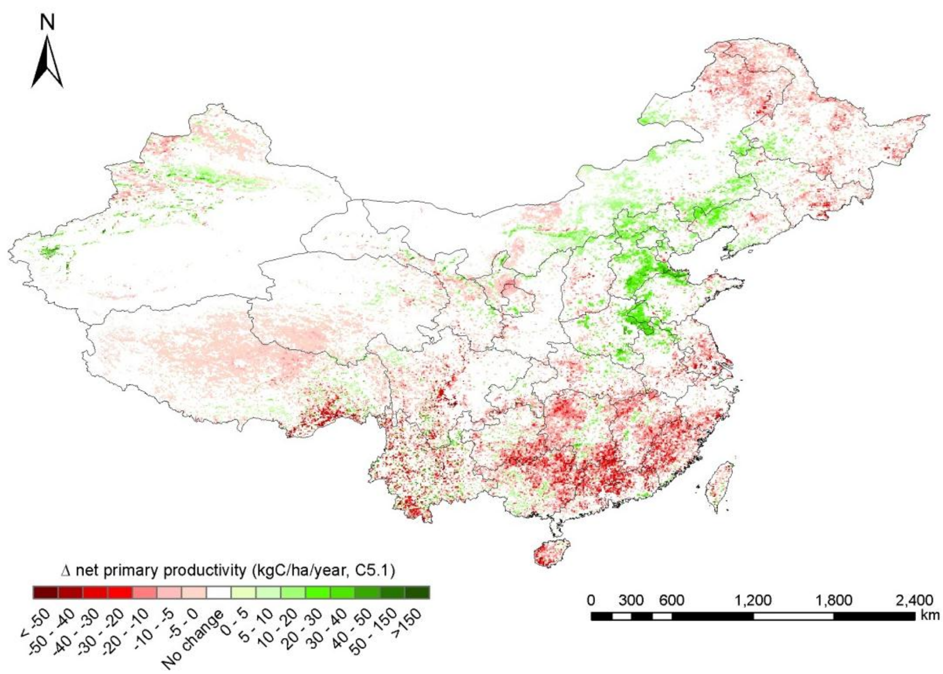
Across China, geo-hazards, floods in particular, are responsible for many hundreds, sometimes thousands of deaths and cost billions of RMB yuan annually. The response has included training courses in rural geo-hazard prevention and control, reaching nearly three million people in 10 000 villages all over China; geo-hazard investigations in hill country and cities; flood monitoring and early warning and nationwide meteorological forecasts; geo-hazard monitoring and demonstration stations in Wuhan, Fengjie and Chongqing; and emergency relocation of tens of thousands of people. For instance, in the Three Gorges Reservoir area, there were some 1 700 geo-hazard control projects, 1 897 landslide monitoring and prevention stations and 160 000 mass-movement monitoring and interventions by the end of 2007. These engineering responses are reckoned to have a net annual benefit of 550 million yuan and are backed up by continued investment in geo-sciences that provides a growing cadre of competent professionals.

Land degradation

China suffers more than most countries in terms of the extent and economic impact of land degradation and more than any in the number of people affected (Bai & Dent 2009, Bai & others 2013). In 1999, direct losses from land degradation were estimated at $7.7 billion (4% of GDP) and indirect losses at $31 billion. The cost of remediation is hard to quantify but current investment appears to be an order of magnitude less than the size of the problem (ADB 2002). Dry lands, especially in North China, have attracted most attention (Zhao S 1991, Dregne 2002) but their productivity declines from a low base and livelihoods in these areas are always precarious.

Satellite measurements of climate-adjusted net primary productivity (NPP) over the period 1981-2006 (Figure 6) suggest that 24 per cent of the country suffered degradation over the last quarter century – 14 per cent at high confidence. Contrary to received wisdom, most of the degrading areas are not in the dry north and west but in the wetter and more densely populated south-east. NPP has been increasing across 17 per cent of the country, mostly in dry lands that have benefitted from major land improvement schemes. Over the same period, China's unprecedented economic development was accompanied by equally unprecedented growth of urban areas and infrastructure which accounts for much of the decline of NPP in rapidly developing areas like the Yangtze and Pearl River deltas.

Figure 6: Trends in climate-adjusted net primary productivity in China, 1981-2006
(Bai and others 2013, calculated from NAASA GIMMS NDVI data Pinzon and others 2007)



More broadly, comparison with *Global land cover 2000* (JRC 2003) indicates that half of all forest land is degrading (forests make up 35% of the degrading area); 17 per cent of cropland (croplands make up 14% of degrading land); 28 per cent of grassland and sparse scrub is degrading (34% of degrading land). Comparison with FAO Land use systems (FAO 2008) gives similar proportions; interestingly, areas with irrigation and legal protection fare no better than the average. China is one of the very few places where the effects of individual land reclamation and improvement schemes can be seen on the satellite image. Of the improving area, 47 percent is cropland, 21 per cent grassland and 17 per cent forest.

Land information

Topographic survey

Topographic survey is the responsibility of the State Bureau of Survey and Mapping (SBSM) which has completed 602 000 topographic sheets, 164 000 geodetic survey points, 750 000 km^2 of aerial survey and 2.29 million km^2 of satellite imagery. These provide topographic data for major engineering projects, construction of new towns and villages, land use planning, defence and security, demarcation of boundaries, and base maps for various purposes. The estimated societal value of completed mapping is 2.84 billion yuan ($0.45 billion). Projects in train include survey of blank areas of the 1:50 000 topographic map in western China, updating the 1:50 000 national geographic information database, a digital urban geospatial framework, and a high-resolution stereo-mapping satellite. The recently promulgated *Surveying and Mapping Law* includes regulations for professional certification and supervision and management of on-line geographic information security.

Land resources

It is well-recognised that land resources survey and monitoring underpin policy, planning and decision-making. The Chinese Academy of Land Surveying and Planning, under the MLR, directs land resources surveys carried out by provincial, prefectural, and county agencies by professionally trained staff who make use of remote sensing, GIS and GPS. Land resources survey has been completed at scale 1:10 000 for 2 million km^2, at 1:50 000 for 620 000 km^2, and at 1:500 000 for 1.19 million km^2; and a market survey at scale 1:10,000 has been completed for 99 800 km^2 (2731 land resources survey reports are extant); monitoring programs have been established to serve land administration, law enforcement, and the annual review of land-use change.

To improve the quality of information, MLR has promulgated national standards and established key laboratories of Earth Observation and Mine Space Information and research centres of Applied Engineering, Geographic Information Systems, and Geographic Space Information and Digital Technology in the State Bureau of Surveying and Mapping. There has been a big investment in remote sensing (MLR is a main user of the Sino-Brazilian earth resources satellites) and land resources information is being brought on-line to support on-line examination and approval of construction land, and administration of exploration and mining rights.

Soil survey

As a separate activity, soil surveys are undertaken by the State Key Laboratory of Soil and Sustainable Agriculture of the Institute of Soil Science, Chinese Academy of Sciences, in Nanjing. Besides local and regional mapping for agriculture, catchment planning and soil and water conservation, there have been two nationwide soil surveys. A three-year study, beginning in 1958, mapped the country's arable land (excluding Tibet and Taiwan) at scale 1:2.5million using an agricultural soil classification, and produced a National Soil Fertility Overview at scale 1:4million based on farmers’ experience. This information did not meet the needs of agricultural development: data on arable land were unreliable and there was little information on forest, pasture and wasteland. In any case, the information was not applied during the Great Cultural Revolution when scientists, as opposed to their knowledge, were put to work in the fields.

In 1979, the State Council ordered the Second National Soil Survey. This took 16 years and involved more than 84 000 soil scientists and managers, as well as technical workers, guided by uniform technical specifications and beginning with detailed investigation at the county and township level. Preliminary air photo and satellite image interpretation provided a consistent basis for the fieldwork. A lot of the mapping was at large scale: in South China most agricultural regions were mapped at scale 1:10 000, in North China at 1:10 000 or 1:25 000; forest or pastoral areas were mapped at 1:50 000; grasslands and deserts in the Xizang Plateau and Xinjiang at 1:200 000. The detailed maps were then scaled, step by step, to county maps at 1:50 000, prefectures at 1:100 000 to 1:200 000, provincial/autonomous regions at scales 1:500 000 and 1:1 million. Soils were classified according to the Chinese system that takes account of soil forming factors, processes and properties (Shi & others 2004); the maps show soil types, resource use, nutrient status, and zoning for soil improvement.

Compilation of a national soil map at scale 1:1million began in 1986. As a first step, seven representative regions were selected and comparisons made between different mapping units and interpretations. Based on review of the sample maps and extant small-scale soil maps, *Criteria for plotting China’s 1:1 million* *soil map* were formulated in 1990. Definitive compilation started in 1992 based on provincial-level soil maps, topographic maps and satellite images; also making extensive reference to soil records, geological maps, forest distribution maps, land use maps and older soil survey data. Soil maps of Taiwan, Hong Kong and Macao were made by interpretation of satellite images with reference to the soil distribution pattern of Guangdong Province. The national map comprises 64 sheets and 909 soil mapping units, mostly families grouped into sub-groups (235), great groups (61) and orders (12), and 4 non-soil formations; the minimum delineations are 25 mm^2 (25 km^2 on the ground) for forest and pasture areas, 16 and 4 mm^2 (16 and 4 km^2 on the ground) in agricultural areas and regions of scientific interest. Further aggregation produced maps at scales 1:2.5million and 1:4 million. The 1:4 million map series also includes soil improvement zones, pH, calcium carbonate, soil nitrogen and organic matter, total phosphorus, potassium, boron, and effective manganese, zinc, copper and iron. The six-volume *Soil Series of China* describes nearly 3000 soil series in terms of order, great group, sub-group and soil family; soil parent materials, soil profile and thickness. Each typical soil profile description includes site data, field description of colour, texture, structure, distribution of plant root systems, and related meteorological data, natural vegetation or crops at the site, and productivity. The analytical data vary from soil type to soil type but include particle-size distribution, pH, organic matter, CEC, exchangeable bases, exchangeable H and Al, total N, total P, total K, available P and available K.

All-China mapping is largely complete at scale 1: 50 000 for agricultural areas and 1:250 000 for dry lands. There is a 1:1 million digital soil map which supports research, education, national and regional agricultural production planning, water and forest resources, environment protection and ecological restoration (Shi and others 2011). Work continues on the associated soil database; experienced taxonomists, veterans of the second national soil survey, are matching the data for every archived soil profile with spatial units of the soil map, province-by-province. The *Soil Series of China* is fairly consistent at great group and sub-group level but at the soil family level the names of soil types are not uniform and sometimes differ sharply between soil profiles and spatial units on the soil map. Judgement is required to define accurate links between attribute data of soil profiles and corresponding soil map units, and taxonomists have to refer to soil series records kept in their respective localities.

All the heritage soil data use the Chinese classification with categories like red soil, paddy soil, brown earth and cinnamon soil originating in the 1930s and applied as a mature system since the 1970s. This system is quite different from *Soil Taxonomy* and the *World Reference Base for Soil Resources (WRB)* which makes international comparisons difficult, so the Institute of Soil Science is working up a *Chinese Soil Reference System* based on information gathered from 3000 soil profiles for different series all over the country (published in *Soil Series of China*), correlating respective attributions in *Soil Taxonomy* and *WRB.* International collaboration also includes the EU Framework 7 *e-SOTER* project (2007-12) to develop digital soil and land survey methods.

Soil pollution

Systematic data on soil-environmental quality is required to identify the type, extent and causes of pollution; to assess the risk of contamination; to screen and demonstrate remediation technologies; and to establish regulations for soil pollution control and national standards for the soil environment. A nationwide soil pollution survey was undertaken over 4 years, starting in 2006, led by the Ministry of Environmental Protection with the participation of one thousand organisations and some 20 000 professional and technical personnel. About 214 000 soil samples were taken for analysis of specific heavy metals, arsenic, organochlorine pesticides, polycyclic aromatic hydrocarbons, and phthalates. Outputs include evaluation, status and comparative analysis of the soil environmental quality of the national soil points, soil contamination risk assessment of key areas, planning of remediation of contaminated soils, comprehensive management of the pilot areas, and establishment of a system of soil-environmental quality supervision and management.

Multi-objective regional geochemical survey

Beyond its established role in geological survey, in 2002 the China Geological Survey Bureau launched an exploratory, multi-objective regional geochemical survey in Guangdong, Hubei, Sichuan. Funding of 6.7 billion yuan was provided by MLR and Provincial Governments of Zhejiang, Sichuan and Hunan; 18 other provinces and autonomous regions provided local funds of 3.6 billion yuan; and over the period 2005-2008 (on instructions of Premier Wen Jiabao) the Ministry of Finance contributed a further 2.75 billion yuan to extend the survey to 31 provinces, autonomous regions and municipalities. Of the planned 4.5 million km^2, 1.6 million km^2 was complete at the end of 2009 - covering the Eastern Basin of the central plains, lakes and wetlands, offshore shoals, the Loess Plateau and major agricultural producing areas. More than 500 scientific and technical staff have been involved; more than 100 000 people collected 600 000 samples; 23 laboratories were set up for analysis of 54 elements (32.4 million elemental determinations) providing a systematic identification of the geochemical conditions in the economically and ecologically important areas in the east of the country.

Based on problems identified in the survey, an ecological geochemical evaluation was made in the basins of the Yangtze River, Yellow River, the northeast plains, and coastal economic zone. Attention has been given, on the one hand, to soil fertility and, on the other hand to heavy-metals pollution and their ramifications. Further assessments under projects at provincial and county-level have considered prospects for *green* or *ecological* production in advantageous areas and rational application of fertilizers - expected to add economic benefits of up to one hundred billion yuan.

Scientific developments include specifications and technical requirements of the geochemical assessment of soil quality, and an eco-geochemical database that can be used to for explore source, migration path, ecological effects of pollutants, prediction and early warning. Investigations of Quaternary sediments and soil parent materials have added new parameters for geological mapping; and anomalies provide clues for energy and minerals development. Systematic acquisition of precise soil organic carbon data for farmlands indicates potential for carbon sequestration.

Nepal

Area 14 181 square miles, Population 28 196 000

With Ajay B Mathema

Context

Nepal is a poor country. Two thirds of the active population is employed in agriculture (DOA 2011), contributing one third of GDP (UNIDO 2009), but more than 90 per cent of the people depend on the land for their daily needs and 45 per cent are below the absolute poverty line.

Forest still occupies about 40 per cent of the country (DFRS 2002) and plays an important role in Nepalese life; it is an integral part of the farming system, providing forage, fuel, and timber for construction and implements (Acharya & Dangi 2009). Only 27 per cent of the country is cultivable and about 20 per cent is actually cultivated (Kenting Earth Sciences 1986). For all their importance, land resources are poorly managed. Food production is falling: Nepal is now a net food importer. Constraints include low investment; high dependence on water-intensive crops, particularly rice; lack of focus on natural resources both as regards production and ecosystem services; and loss of prime farmland to urban development - high real estate prices make urban development more attractive for both government and private investors. Over the period 1981-2006, 39 per cent of the land was degrading and these areas support almost half of the population (Bai and others 2008). Forests and scrubland are being encroached at annual rates of 1.7 and 0.5 per cent, respectively (MoFSC 2002).

Land resources information

<u>Topographic survey</u>

Topographic survey is complete over most of the country with 1:25 000 scale maps of the plains and middle mountains and 1:50 000 for the mountains. Under the National Topographic Database Program, begun in 1998, the Survey Department is making data available in digital GIS format: geodesy and topography, hydrography, administrative boundaries, transport infrastructure and utilities, built-up areas, land cover and designated areas (Chatakuli 2003, Sharma and Acharya 2004).

<u>Cadastre</u>

Systematic recording of land began in 1964 upon promulgation of the Land Reform Act 1962. Survey offices are established in all 75 Districts and district cadastral maps were completed by 2000 and linked within a national geodetic framework. The Land Reform Information System (LRIS) project under the Ministry of Land Reform and Management is developing a GIS for land ownership, tenancy and cadastre.

<u>Land resources</u>

Land resources mapping was undertaken between 1976 and 1984 by a joint project between the Survey Department and the Government of Canada. A multidisciplinary team led by the consultants Kentings mapped land systems, land use, land capability, and geology at scales between 1:25 000 and 1: 100 000; and training was provided for counterpart staff. Thirteen volumes of supporting reports include climate, water resources, agriculture and forestry, economics and a summary report (Kenting Earth Sciences 1986) but no provision was made for verification, updating, or sharing the data with other institutions. Initially, the information was used in various plans and policies including the Master Plan for the Forestry Sector (MoFSC 1986) and National Conservation Strategy (adopted in 1988), but it is now more than thirty years old and held only on paper.

Forest Resources

Management of forest information is poor. Data are scattered across different organisations and have not been systematically updated. With Finnish assistance, a National Forest Inventory was implemented by the Department of Forest Research and Survey under the Ministry of Forests and Soil Conservation, using remote sensing and GIS technology. The project began in the early 1990s and was complete in 1998. Compared with the 1976-84 Land Resource Mapping, the inventory showed a decrease in the total area of forest and shrub land of 2 per cent (DFRS 2002). The information was used in forest sector strategy as well as related strategies like the Nepal Biodiversity Strategy (MoFSC 2002). However, the inventory focused on standing biomass and timber volumes; little effort was expended on biodiversity or non-timber forest products; and no survey has properly demarcated the boundaries of community forests (invisible to remote sensing) which are always a bone of contention.

Social, political and economic changes place new demands on the forest and there is an urgent need for data at several levels and scales including, as well as conventional forest and tree characteristics, data for dead wood, biomass and soil carbon, biodiversity, and human impacts (Kandel 2011). In a further bilateral agreement with Finland, 2010-2014, a *National Forest Resource Assessment* is under way to strengthen institutional capacity in the Department of Forest Research and Survey, maintain forest sector information for the whole country, develop national baseline forest data, and share these across government and with related forestry organisations. District-level information is beyond the scope of the present project but the high-resolution satellite imagery and inventory methods could be scaled up for district and management-level inventories.

Use of land resources information

It is hard to judge what use is actually made of the land resources information that exists. Since 1956, Nepal has produced periodic five-year development plans (the tenth is now in effect) which provide the only formal basis for land use and the development of urban areas and infrastructure. But new public and private initiatives appear without formal planning, consultation or review; the absence of public investment planning and inter-agency coordination are, themselves, a major cause of land use problems. Even if land use regulations were enacted, there would be formidable problems with implementation because there is no workable institutional structure or planning capacity. Constraints on the delivery of useful information for policy planning follow from the above: the lack of clear, consistent demand from policy-makers; the absence of effective management institutions and an organizational framework; lack of compatibility of GIS-based land resources information systems; weak professional and technical capacity; and lack of money. Every ambitious land resources survey has depended on outside assistance and funds (Berry & others 1974, Kenting Earth Sciences 1986, and the recent Finnish forestry projects) and the Government continues to seek bilateral and multilateral technical and financial support. But experience shows the limitations of such projects: they are one-off's, not part of any consistent information-for-decision makers strategy; they leave no strong institutional legacy; the results are not owned, and not used, by institutions that have not received that support - even if they know about them; and staff trained up in the project find better prospects elsewhere.

AUSTRALIA

Area 2 969 907 square miles (7 692 024 sq. km), Population 20 743 000

This case study draws extensively on Campbell (2008) and the Soils Research, Development and Extension Working Group (2011).

The driest continent

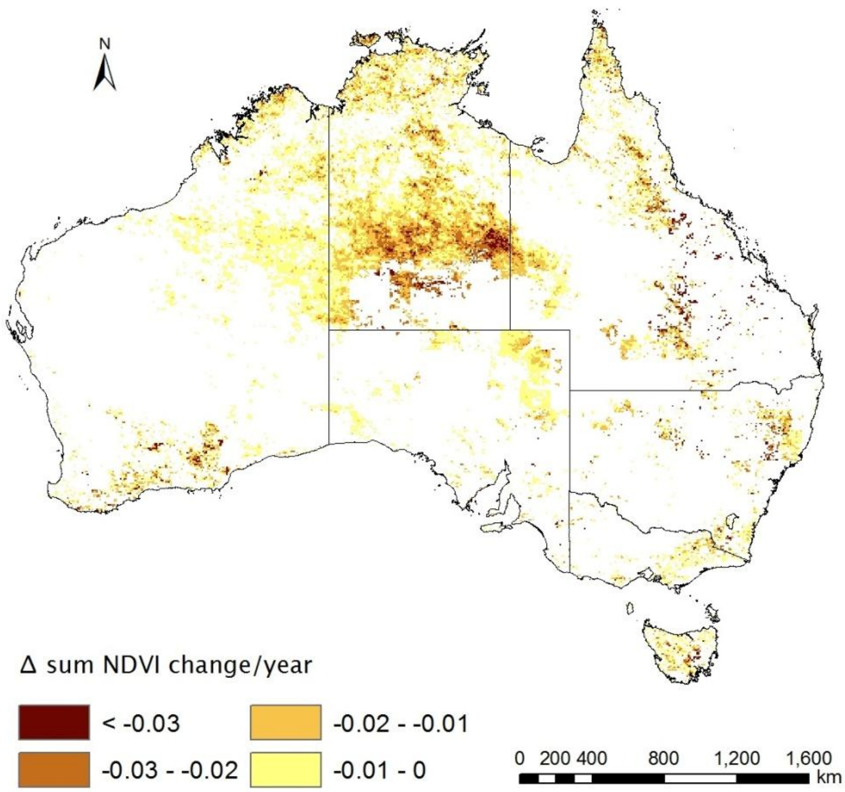
Australia stands out from other continents: by far the smallest, flattest, driest, least-fertile and, yet, biologically astonishing. Until European settlement 250 years ago, it supported the fewest people but most distinctive societies. Still with relatively few people, Australia is a major exporter of primary products. As well as minerals, 60 per cent by volume of farm production (valued at $A23 billion in 2008/9) is exported (DAFF 2009). Growing global demand for primary products presents further opportunities but the country will need to reallocate its resources to serve its own growing population and Australia is uniquely exposed to climate change. Beyond food security, current policy priorities are to protect ecosystem services, improve water use and management, tackle the problems of crop nutrition and reliance on high-energy fertilizer inputs, reduce greenhouse gas emissions, and manage the soils to store more carbon (Thompson 2011).

The capricious rainfall is driven by the non-annual El Nino-Southern Ocean cycle. Most of the country receives less than 20 inches (500mm) a year and water resources are highly leveraged. During the recent century drought, the Murray, Australia's biggest river, failed to reach the sea and water was cut off from long-established irrigation areas. The *Australian Agriculture Assessment* (NLWRA 2001a) highlights:

- Extensive soils of low organic content, poorly structured and commonly water-repellent – conditions made worse by agricultural practices
- Widespread soils with a clay pan that restricts drainage and rooting, often underlying a nutrient-poor bleached layer
- More-fertile cracking clays have physical limitations that are hard to manage
- Salty and sodic soils are more common than in other continents (sodicity affects about 28 per cent of the country)
- The southern croplands are hemmed in by the wind-blown sands of the arid interior
- The remaining ancient land surfaces, particularly in northern Australia, carry strongly weathered, nutrient-poor soils.

There have been local successes of improved management, such as maintaining a surface cover of trash under sugar cane. Even so, tracts of land are scarred by soil erosion and liming is an order of magnitude less than needed to remedy soil acidity; 29-60 million ha have reached a growth-limiting pH of 4.8 and a further 14-39 million ha are too acid for acid-sensitive crops (pH<5.5). At the time of the *Australian dryland salinity assessment* (NLWRA 2001b), salinity was perceived as a threat to 17 million ha of farmland as well as urban infrastructure and water supplies. Since then, prolonged drought has curtailed salt discharge but salt concentrations in the streams have increased; in a drying climate this trend will continue. Figure 7 shows negative trends in NDVI, the greenness index, as a proxy measure of land degradation over the period 1981-2006 (Bai and others 2008). The affected area is almost 2million km^2 (more than 6 percent of the global degrading area), most conspicuously in the Tanami Desert and sub-tropical north but there is, also, significant degradation of rain-fed farmlands along the western slopes of the Great Dividing Range and in Western Australia.

Figure 7: Australia – negative RUE-adjusted NDVI trends, 1981-2006



Some of the more recalcitrant issues stem from the on-going attempt to adapt imported farming systems to the Australian landscape[23]: the pressing need to restore hydrological balance, maintain water supplies to burgeoning cities and far-flung rural communities, and to contain salinity; to drought-proof soils and farming systems, restore soil organic matter and soil health; and conserve viable rangelands, forests and wetlands. It is hard to see how these problems can be solved without new and distinctively Australian management practices, perhaps modelled on the natural ecosystems that evolved in response to local conditions - but this will require better information and practitioners able to develop and apply new farming systems.

Australia is uniquely exposed to climate change (Garnaut Climate Change Review 2007). The latest projections indicate stronger seasonality in the parts of the country where most people live: hotter, somewhat wetter but with a shorter wet season and more intense storms. The odds on a good growing season will lengthen; compared to the situation without climate change, agricultural exports are projected to decline by 11-63 per cent by 2030 and by 15-79 per cent by 2050 (Gunasekera and others 2007). An analysis of impacts on water resources in the Murray Darling basin predicts that, by 2070, water yields in the Murrumbidgee River will drop by as much as 48 per cent; salt discharge will decrease by 30 per cent, but end-of-valley salt concentrations in the river will increase by 11 per cent; with comparable figures for other basins (Austin and others 2006).

[23] An ironic exception has been the non-adoption of regular liming of acidic soils – a practice adopted by farmers in Europe since the Agricultural Revolution in the 18th century (Wallerius 1761).

Land resources management in a Federal system

Under the Constitution, land and water management is the responsibility of the States and Territories - each with its own legislation, agencies, and shifting priorities. Commonwealth agencies include the Commonwealth Scientific and Industrial Research Organisation, CSIRO (in which the Division of Land and Water has absorbed previous Divisions of Soils, Water, and Tropical Crops and Pasture), Geosciences Australia, and the Australian Bureau of Applied Resource Economics, ABARES (incorporating the former Bureau of Rural Sciences).

The Golden Age saw world-leading applied research in soils (Northcote 1960), land systems (Christian & Stewart 1952), forests (Vanclay & Preston 1989) and rangeland. But there has been no continuity of direction or funding; the information stream has become fragmented and haphazard; and the States have struggled to provide adequate funds. State and Territory agencies remain the largest budget providers (in the case of soils R&D, 42 per cent of a total of $124 million for 2010-11) but there has been a consistent trend of increasing Commonwealth funding and influence over natural resources management. The 1983 National Soil Conservation Program allocated $A20million over four years; Commonwealth funding surged to $340million with the Decade of Landcare in 1989; in 1996, the National Heritage Trust (NHT) was established with a billion dollar budget and a further $A300 million in 2003-4, primarily as small grants. As NHT programs rolled out, there was a felt need for more focus on the big issues: the National Action Plan for Salinity and Water Quality, in 2001, brought $1.4 billion over 7 years; the National Water Initiative $2 billion in 2003 and the $A10 billion National Plan for Water Security in 2007.

Even when Commonwealth funds have been earmarked, getting things done across state boundaries requires hard bargaining. For instance, when the Commonwealth allocated an unprecedented $A 1.4 billion for a National Action Plan for Salinity and Water Quality in 2001, Premier Howard’s need to secure support from the States require disbursement of most of the funds to state budgets - where they were dissipated without tangible impact on salinity. The later National Plan for Water Security amounted to a Commonwealth takeover of the management of water resources, including replacement of the collaborative inter-state Murray Darling Basin Commission by an appointed Murray Darling Basin Authority. A National Primary Industries Research and Development and Extension Framework is also being developed for investment in 14 industry and 7 cross-industry sectors, amounting to approximately $A1.6 billion annually (SRDE Working Group 2011).

Central direction has been accompanied by a focus on headline issues - salinity, drought, climate change - as opposed to maintaining a balanced capacity across the whole field of land resources. The last 20 years has also seen a shift of public funds to new regional institutions positioned between local and state government. The intent was to respond to regionally important issues in an integrated way, at an appropriate scale, and to get the right people working together. But the process has diverted limited funds away from career scientists towards new regional structures which, lacking coherent land resources information or the capacity to interpret and apply such information, have struggled to apply up-to-date science and best practice (RM Consulting Group 2006).

Land resources information

(After McKenzie and others 2008, Mutendeudzi and Stafford-Bell 2011, SRDE Working Group 2011)

<u>Climate and hydrology</u>

Weather, climate and hydrological services are provided by the Bureau of Meteorology; data from 4 600 meteorological stations are available from the website (Bureau of Meteorology 2011). Together with the Queensland Department of Natural Resources and Water, the Bureau has delivered two sophisticated and popular interpolations that provide continuous-field, daily climate data adjusted for relief and aspect. The *Data Drill* (Jeffrey and others 2001) estimates daily weather since 1957 on a 0.05^{o} (about 5km) grid but accuracy is low where the station intensity is low, or low relative to the climatic gradient. The *Patched Point Dataset* uses interpolated data to fill gaps in the observational record and may be used where more accurate data are needed for analysis or simulation, for instance in hydrological modelling.

Meteorological data, worldwide, benefit from the strong demands of the military, shipping and aviation. In contrast, the history of hydrological data is one of stops and starts, so policy and management depend heavily on modelling.[24] ABARES holds information on groundwater hydrology and salinity compiled from Commonwealth drilling programs and modelling over many years, including trends and depths around high-value environmental and agricultural assets. Stream gauging is patchy but the States have fully maintained networks that monitor water quality. In 2010, the Bureau of Meteorology began consolidating data on river flows, groundwater, water storage, and water quality from more than 200 organisations into a Water Resources Information System.

Terrain

State survey departments produce good topographic maps at various scales but, for many purposes where quantitative analysis of terrain is wanted or various layers of data combined, paper maps have been superseded by digital elevation models (DEMs) within a computer-based geographic information system (GIS). DEMs for the whole country have progressed from 1/10th degree resolution in 1982 to 1 second (about 30 m) today. The latest DEM from the NASA Shuttle Radar Topographic Mission (SRTM) is publicly available through the Geoscience Australia National Elevation Data Framework (NEDF) portal (http://nedf.ga.gov.au).

DEMs created by remote sensing suffer from voids in areas of high relief, striping, and offsets induced by vegetation (in inland Australia, rivers fringed by remnant native vegetation appear to be raised above the surrounding cleared areas). CSIRO has produced a corrected DEM for the whole country making use of algorithms for stream line contours and vegetation mapping to correct for offsets (Gallant 2011). Useful products include DEM-S, a bald-earth elevation model for applications where connectivity of flow is not the primary concern (such as calculation of slopes and topographic position); stripes and voids are removed, offsets due to trees treated, and noise reduced by adaptive smoothing. For applications where hydrological connectivity is needed, such as calculation of contributing areas and catchment delineation, DEM-H applies drainage enforcement using surveyed stream lines.

Derived products including slope, aspect, curvatures, topographic position, relief, contributing area and wetness index are key inputs for predicting soils and ecological patterns - foreshadowed by Wilford and others (2001) who combined landform with soil parent material mapped by airborne geophysics to predict soils and salinity. Countrywide predictions of key soil properties on a 3-second grid, using the 1-second terrain layers, are being developed for *GlobalSoilMap;* catchments and stream lines derived from DEM-H

[24] The National Audit (NLWRA 2002) cites the 1887 Royal Commission into water conservation In New South Wales: '*On entering our duties we found that information available regarding our rivers was meagre and fragmentary, and in some points public opinion was in danger of being misled by statements and theories which there was ample evidence to refute ... We beg to recommend that the maintenance of river gauge records as extended by us be made more complete, and the records kept continuously and in a careful and systematic manner.'* And, one hundred and fourteen years later, the Australian Parliament's inquiry into catchment management (2001) noted: *'From the evidence it has received, it is convinced that there is not enough information to formulate policies and strategies ... It is also clear that ineffective use of data has limited the success of current catchment management programs … the Committee concludes that, while there is an expanding body of information in this area, it is often inaccessible, patchy, uncoordinated and uncollated.*'

will form the basis for future versions of the Australian Hydrological Geospatial Fabric (http://www.bom.gov.au/water/geofabric/index.shtml). New applications emerge with each improvement in resolution and accuracy. Airborne LIDAR already provides high-precision terrain data, with vertical accuracy better than 20cm at better than 1m horizontal resolution, which can distinguish discrete vegetation layers. These data are available for some urban areas, coastal lowlands, wetlands and floodplains where the accuracy justifies the cost.

Geology and regolith

(After Taylor, Pain and Ryan 2008)

Although their resources are dwarfed by the multinational minerals industry, Geosciences Australia and the State geological surveys maintain systematic scientific data and provide advice to decision-makers. Digital geological information maintained by Geosciences Australia may be located through the Australian Government Geoscience Portal (2011) and airborne geophysical data and reports acquired under the National Action Plan for Salinity and Water Quality are accessible through the ABARES web site. Geological mapping is available for the whole of the country, at least at first pass, at scale 1:250 000. For certain areas, maps are complete at scale 1:100 000 and, occasionally, 1:25 000. Other maps are available from mineral exploration leases via completion reports lodged with State and Territory geological surveys.

In common with geological surveys worldwide, mapping supports mineral exploration and deals mainly with bedrock geology, not the weathered regolith. Geological mapping units are based on lithology but, for reasons of scale, are usually shown as *Formations* or *Groups* comprising a variety of rock types that behave very differently - commonly grouped according to age which is irrelevant to structure, landform, soil parent material and economic value. Regolith-landform maps are constructed on the same assumption as soil-landscape maps - that regolith materials on similar landforms will be similar (*e.g.* Pain and others 1994, Chan and Fleming 1995). Where there has been detailed fieldwork, fine-scale detail on the three-dimensional pattern of regolith is available (*e.g.* Lawrie and others 2000).

Vegetation

(After Thakway, Nelder and Bolton 2008)

Consistent, reliable vegetation data are needed for developing and implementing policies embracing sustainable management of wetlands, rangeland and forests (for instance Regional Forest Agreements in New South Wales, Victoria, Tasmania and Western Australia); control of land degradation; conservation of biodiversity; fire management; and control of pests and weeds. Required information includes lists of species, maps of both species distribution and vegetation types, and a range of supporting data. Vegetation mapping is also required for the administration of laws on vegetation clearing promulgated in recent years by most States. For instance in Queensland, regional ecosystem maps are certified legal documents; the extent of vegetation shown determines conservation status, and unauthorised tree clearing incurs substantial fines.

In the States and Territories, departments of natural resources are responsible for vegetation survey. At the Commonwealth level, the Department of Agriculture, Fisheries and Forestry and the Department of Environment and Heritage coordinate information and reporting. Since the late 1940s, various survey, classification and mapping systems have been used so it can be difficult to compare or combine different datasets - although systems have been introduced to translate and combine datasets (*e.g.* AUSLIG 1990, ESCAVI 2003). Some forest datasets are available through ABARES, some of these with licence restrictions.

Land use
(After Lesslie, Barson and Randall 2008)

Changes in land use and management profoundly affect land and water resources. Reliable, up-to-date information is needed to respond to issues such as salinity and water quality, stream sedimentation, protection of infrastructure, and conservation of biodiversity. Before the 1980s, land use information was derived from soils and land systems surveys. Subsequently, land use has been mapped by remote sensing supplemented by biophysical, social and economic data (*e.g.* Natmap 1980 1982, Victorian Dept Water Resources 1989). Since 1992-93, a biennial national overview has been compiled from AVHRR satellite data combined with Australian Bureau of Statistics *Agricultural Census* data for farmland and extant data for other areas, mainly at scale1:250 000.

The Australian Collaborative Land Use Mapping Program has completed mapping at scale 1:25 000 in parts of Tasmania and around Melbourne, Perth, Sydney and Darwin; 1:50 000 in coastal areas experiencing rapid change, 1:100 000 across broad-acre farmland and 1:250 000 across the pastoral areas (Barson and others 2000, BRS 2006). Primary and secondary classes relate to land use defined in terms of management objectives: conservation and natural environments, production from relatively natural environments (grazing natural vegetation or forestry), broad-acre agriculture and plantations (plantation forestry, grazing modified pastures, cropping), irrigated agriculture and plantations, intensive uses (*e.g.* horticulture, intensive animal production) and water. Further data for commodities, land management practices or vegetation information are gathered as required.

Soils and land systems
(After Gibbons 1983 and McKenzie and others 2008)

In 1827, William Dutton, a sealer, anchored in Portland Bay to take on fresh water. He found a stretch of dark, friable soil along the cliff tops and, later, ploughed the first furrow in Victoria to plant his crops. It was not long before Departments of Lands, Agriculture and Minerals of the various Colonies began surveys for Settlement Boards at 40 chains[25] to the inch (1:31 680). Later maps included suitability ratings for agricultural settlement. From the 1890s, Guthrie and Jensen collated farm data for nutrient status, soil texture and water-holding capacity, and presented the information in a standardised way for eastern New South Wales (Jensen 1914) and, later, parts of Queensland - though at a very small scale.

The door to modern soil surveys was opened in 1925 by the arrival of JA Prescott, already familiar with the fully fledged American and Russian approaches, and the recommendation of the Council for Scientific and Industrial Research on which he served for ‘the first organized soil survey’. Resources were never available to emulate the USA’s nationwide detailed soil survey but its concepts of *soil series, type and phase* were adopted for surveys of irrigation areas, beginning with Renmark in South Australia, where traverses were made at close intervals with borings to six feet (Taylor and England 1929). The first generation of soil surveys, carried out between 1927 and 1941 was so efficacious that in 1944 the Rural Reconstruction Committee recommended that all future irrigation schemes should be preceded by detailed soil surveys: this became government policy (Blackburn 1962).

The same approach was adapted for broad-acre farmland and, with prodigious effort, 1.5million acres in Western Australia were surveyed for opening up wheat farms (Teakle 1939, Teakle and others 1940). But it was always too slow; there were too many acres and too few surveyors. Small-scale mapping of *Great soil groups* didn’t provide good predictions of soil attributes but, following Milne (1935/6) in East Africa, surveyors recognised relationships between the various soils in a landscape and, from detailed

[25] 1 chain = 22 yards

examination of representative areas, Butler and others (1942) mapped *soil associations*. Knowing the pattern enabled prediction of the component soils and, for the same effort, greater coverage could be achieved without corresponding reduction in content and precision. Component soils were identified at taxonomic levels from *soil types* to *great soil groups*. Later, seeking better predictive ability, Butler (1959) again led the way in recognising the layering of former land surfaces, which may be buried or partially exposed in the old Australian landscape.

The outstanding Australian contribution to land resources survey was the conceptual leap from surveys of soil to surveys of land. Christian and Stewart (1952) defined *land systems* as a recurring pattern of landforms, soils and vegetation identified on air photos; the land system might be subdivided into *land facets* - mappable entities (though not usually mapped out) of uniform landform, soil and vegetation. The approach depends on presumed correlations of landscape features observable by remote sensing; field observations are not primarily to locate boundaries but to identify soils and vegetation within areas delineated on air photos. A further premise is that land use is constrained by the combined effect of several land attributes – so the same map can be interpreted for different purposes. Land systems surveys at scales 1:250 000 and 1:500 000 were first applied to northern Australia where much natural vegetation was intact. Rapid appraisals were made at low cost, since large areas were mapped with little field work, and the holistic approach involving a team of specialists and extension staff arguably enabled a more realistic assessment of possible land uses and hazards (Northcote 1984).

The Golden Age was driven by demand for information for frontier settlement and more intensive use of established farmland. But demand waned and there was a loss of confidence in what land resources survey could actually deliver. Emphasis changed to risk-avoidance and issues of the day which have included salinity - notably Northcote and Skene's (1972) assessment of salinity at scale 1:5 million, Rowan's 1971mapping of salt-affected soils in north-western Victoria at scale 1:375 000, and the recent application of airborne geophysics to map salinity and water resources (Dent 2007); also the acid-sulphate risk mapping of coastal areas in New South Wales, more-intensive activity in Queensland and, later, inland acid sulphate soils, particularly in the Murray Darling Basin (Fitzpatrick and others 2009).

Status of land resources information

Until about 1990, land resources information was collected essentially for agricultural development using methods developed in the 1940s and 50s. With a continent to map, a wide range of environments and contrasting levels of development and no centralised organisation, individualists were able to apply off-beat approaches that matched particular needs and circumstances. Beckett and Bie (1978) noted: 'Australia has produced an extraordinarily wide range of soil and land system maps. Together these provide a major contribution to soil survey methodology.' But the scale and information content was rarely good enough for the decisions that had to be made and still falls short of minimum requirements - and well below that achieved by comparable developed countries. CSIRO's assessment of the minimum information need (Figure 8) and what has actually been accomplished don't bear comparison with the completion, thirty years ago, of nationwide soil survey of the USA (apart from Alaska) at scale1:20 000. Old data are being flogged to death, revealing their limitations; as they are derived from project-specific studies for various purposes, they are hard to standardise and integrate for different applications.

Apart from early irrigation schemes and land systems mapping by CSIRO, surveys have been undertaken by State and Territory agencies and coverage at the required scale was never achieved before they were scaled back or discontinued. Only 30-40 per cent of broad-acre cropland has even the minimum coverage and much of this lacks the full suite of attributes. Rangelands have been mapped as land systems with assessment of land capability but little information about their soils.

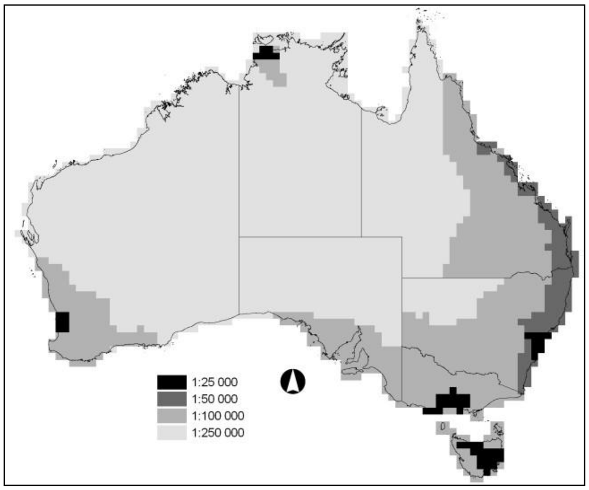


Figure 8a: Suggested level of soil mapping for Australia

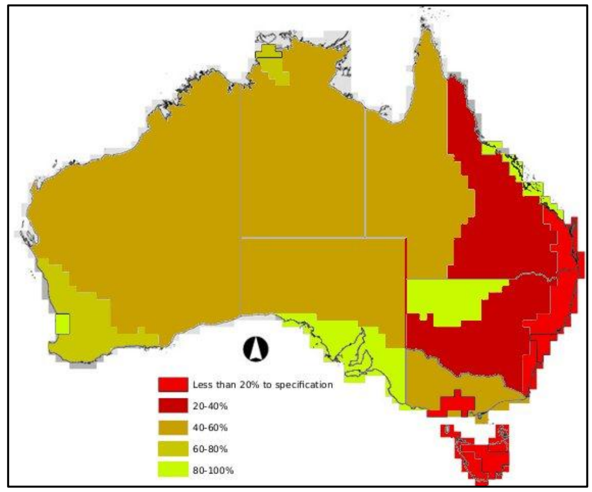


Figure 8b: Broad estimate of the extent to which current soil information coverage meets required coverage and resolution

Western Australia has correlated soil maps for 60 per cent of its farmland, mostly at scale 1:100 000 with database recognition of the unmapped components of each mapping unit; about half of the dry interior is mapped at 1:250 000 but with only rudimentary soil attribution. South Australia has mapped soil landscapes across all the southern cropland at 1:50 000 or 1:100 000, recording a comprehensive set of soil attributes for the unmapped landscape components; about half of the dry interior is mapped at 1:250 000. Victoria and Tasmania lie almost entirely within the intensively farmed zone but only half of Victoria is mapped at 1:100 000, mostly not correlated, and nearly all mapping in Tasmania is at broader scales, dating back to 1930-1970. New South Wales and Queensland have challenging requirements of extensive high-resolution mapping that will need significant further surveys. However, there have been notable accomplishments such as the detailed mapping of the intensively managed coastal agricultural areas and some sections of the inland cropland of Queensland. In Northern Territory, the early focus was on regional mapping of the Daly River and northern coastal plain and detailed mapping for peri-urban and horticultural development around Darwin; broad-scale mapping of pastoral lands in Victoria River, the Berkley Tableland and the dry south was accomplished in the 1990s.

Nowadays, soil information is needed for many purposes beyond primary land use - in town planning, civil engineering, environmental management and forensics; emerging issues include the competing interests of farmers and miners in good cropland and the impacts of coal-seam gas exploitation. But as applications have increased, investment in survey and data management has been withdrawn and gaps in capacity have opened that will be hard to plug when the expertise is lost. State agencies have applied information technology to make the most of their discontinuous data and the Australian Collaborative Land Evaluation Program has tackled the mismatch of procedures and information content by agreeing national standards. A start has been made with collation and translation of the best-available coverage to on-line output in the Australian Soil Resource Information System (ASRIS), which is hosted by CSIRO. ASRIS is designed to satisfy the needs of modellers and, notionally, planners for consistent national estimates of soil functional attributes like available water capacity and soil carbon storage. However, transfer of State data to ASRIS is far from complete. No secure funding has been forthcoming and CSIRO struggles to maintain the system - let alone make it usable by policy makers and land managers.

In the late 1990s, CSIRO attempted, unsuccessfully, to model soil distributions at a fine scale from the existing point data and the digital terrain information available at the time; means were not available to integrate the legacy soil maps. Availability of a 30m-resolution DEM and derived slope, aspect, curvatures, topographic position, contributing area and wetness index, together with detailed rainfall models, has encouraged a new attempt to model soil patterns countrywide at 90m resolution as part of *GlobalSoilMap* - but significant national funding is not forthcoming.

Many issues of degradation of natural resources and remedial actions that should be taken urgently were identified in a series of reports by the National Land and Water Resources Audit: *Australian Agricultural Assessment, Australian Dryland Salinity Assessment, Australian Native Vegetation Assessment,* and *Australian Natural Resources Information* (NLWRA 2001a, b, c, 2002). National, issue-based committees were set up to draw on expert assistance for this task. The National Committee on Soils and Terrain (Campbell 2008) argued for a re-think of soils and land use policies in the light of:

- The critical role of soils and soil management in the water balance (in the context of the recent extreme drought and the likelihood that such conditions will become more common)
- Competing claims from land uses other than farming along the coastal fringe
- The need for careful planning of developments in northern Australia as the focus shifts to these less-developed areas with perceived favourable soil and climate
- The role of soil organic matter as a carbon sink and source of emissions
- Hot spots of contamination and leaching of nutrients into surface and groundwaters, such as acid sulphate soil disturbance in urban and peri-urban areas
- The rising costs of energy and phosphate that will put high-input farming systems under stress
- The incomplete soils information base, on-going disinvestment, and erosion of soils expertise within NRM agencies and universities.

Public consultation on the Committee's issues paper (NCST 2009) also highlighted:

- A low level of community and political awareness and understanding of the threats to soil resources and their long-term consequences. There was a call for a renewed campaign for land literacy through the new regional bodies.
- Strong support for a strategic approach to soil management integrated with other natural resources issues (including water and vegetation management) and, at the same time, consideration of soils in other issues (climate, biodiversity and food and water security
- The need for better land and soil information including an effective national soils data infrastructure, a networked soil archive, better access to existing information and a national cooperative soil survey program . ASRIS was identified as a core national resource.
- A dearth of professionals able to interpret and apply soils information - in particular, specialist and local knowledge in soil classification and interpretation. The 2010-11 *Stocktake of Australian soils R&D investment* (SRDE Working Group 2011) enumerated a cadre of 847 professional staff: 108 in extension, 327 in research, 46 in teaching, 161 technical, and 204 postgraduates; 128 in Australian government service, 316 in the State agencies and 371 in tertiary education institutions. Comparison with budget returns suggests that many are employed in roles other than soils R&D.

The findings of the Soil and Terrain Working Group may be extrapolated across the field of renewable land resources. The lack of skilled people on the ground is a threat to both well-informed policy and its implementation. In response, the Primary Industries Standing Committee is now overseeing a definitive overview of the natural resources information required in the national interest and the development of a research, development and extension framework to guide future research.

Lessons

1. Collection and analysis of land resources information has been driven by demand. When there has been a felt need for information, funding has been provided and information has been delivered – but never quickly enough. The Golden Age of land resources surveys, from the end of the Second World War to the 1970s, stemmed from the burgeoning demand for information to support frontier land development and re-development of established farmland to support profitable primary industries, and the willingness of State and Federal governments to create and finance scientific and technical organisations to provide the information. But demand is fickle, depending on commitment of the government of the day and sensitivity to budgetary pressures - all the more acute because information is perceived as enabling rather than immediately exploitable for profit.

2. Australia pays dearly for its devolved government. Cutting the financial cloth into so many pieces has meant that here has never been enough to anticipate natural resources issues; and when an issue arises that demands quality land resources information, successive policy-makers are surprised that the information that they need so urgently is not available. There has never been enough home-grown scientific capacity and, even with the benefit of reinforcements from abroad, science has been spread too thinly for sure-footed decisions.

3. Even so, recent history shows that when an issue assumes enough public and political importance, resources can be made available - even for data collection. But when an issue gets to the top of the list, the scientific and policy community must have credible proposals on the table and a good story showing how interventions will tackle the problem and what the benefits will be. And important stakeholders must have ownership of the plan of action. Thus, the National Action Plan for Salinity and Water Quality was born of long-pent-up perception of salinity as a national issue, and political appreciation at the Commonwealth level that new and potent information from airborne geophysics was the key to cost-effective intervention. Four million dollars was re-allocated *out of the current year's budget* for immediate aerial surveys and an order of magnitude more was earmarked for surveys under the National Action Plan. In the event, most of the initial four million dollars was retained by the Commonwealth Ministry of Agriculture, Forestry and Fisheries; and transfer of the main funds to the States which, by-and-large, did not have ownership of the planned interventions, brought in different local agendas. Cash-starved state institutions wanted to maintain their existing activities so, despite delivering on every technical promise (Dent 2007), only three regional airborne geophysical programs were undertaken (one paid for independently by the Murray Darling Basin Commission). Whether the money was well spent elsewhere is another matter but salinity was soon displaced in the public arena by the longest and most severe drought in Australia's history. Within the new National Plan for Water Security, $A480 million was allocated to develop a nationally consistent water-accounting framework – which will be essential if market-based measures, such as water trading, are to be implemented.

4. Water policy is now in crisis-management. In contrast, a soil policy could be prudent risk management - as well as going a long way towards redeeming the water balance. And yet, there is no funding for staff or operational activities for the Australian Soil Resources Information System (ASRIS), identified as a core national resource by the National Committee on Soils and Terrain. It goes without saying that short-term money can be found for tricky little computer and website enhancers; and state funding is made available, too little and too late, for whatever is the latest natural resources crisis, *e.g.* acidification of the Lower Lakes of the River Murray, and water quality on the Great Barrier Reef.

INSTITUTIONAL PROFILES

Hunting Technical Services

(After Thompson and others 2011)

The record of a private company, Hunting Technical Services, lends insight to the changes and uncertainties in perceptions of development in the second half of the 20th century; how it was supposed to work and what prevented it from working. These perceptions drove the demand for land resources surveys in the years immediately after the Second World War, the shift to integrated development planning that made more complex demands on the providers of information, and disenchantment with planning itself that brought the Golden Age to a close.

In the beginning

The antecedents of Hunting Technical Services (HTS) were Aerofilms, established in 1919, and the Aircraft Operating Company which bought Aerofilms in 1939. Huntings acquired them both in 1943. During the war, company staff worked in the RAF air photo interpretation unit. When commercial life resumed, Huntings foresaw the potential of aerial surveys in mineral exploration and the evaluation of natural resources, and appointed VC Robertson to set up the nucleus of HTS.

Land resources surveys

This was a period of enormous demand for surveys: from big minerals and oil companies that wanted fast, fact-finding surveys of large areas; and from governments, international development agencies and consulting engineers who needed full development appraisal so that work could begin on the ground. It is impossible to overstate the impact of aerial surveys at this time; they raised the surveyor's vantage point from six foot above the ground to that of a hawk - with hawk-eyed definition!

Early surveys of forest and mineral resources in Canada were a great success. They prompted worldwide demand and finance by Canada-Columbo Plan aid: first in Jordan and Iraq; then, in 1957, the first big survey for irrigation development in the Sudan - 12 000 sq. miles in Jebel Marra, accomplished in 5 months (followed by 63 0000 sq.km in Kordofan in 1962-3). In 1959, World Bank-funded work in Pakistan began to tackle the rising water table and salinity in the irrigated flood plain of the Indus. The standard procedure was aerial survey, air photo interpretation, followed up with field traverses by teams with expertise in geology/hydrology, geomorphology/soils and vegetation/land use. HTS in-house skills expanded to include farm planning, soils, land use and ecology; and for big surveys, extra staff were seconded from the home-based surveys and universities. In 1958 HTS moved into purpose-built facilities at Elstree and, in the mid-60s established its own specialist laboratories.

During this period, HTS made notable advances in survey methodology. An example is the adoption of landform mapping units, delineated on air photos, to make sense of the complex variability of soil texture across alluvial plains that had, hitherto, resisted all but very detailed mapping by closely spaced transects (Holmes and Western 1969). This was not surpassed until late in the day when airborne radiometrics was applied to distinguish different soil parent materials (Wilford and others 2001, Dent and others 2013). In contrast, Huntings' use of sideways-looking airborne radar to map perennially cloudy areas (Parry and Trevett 1979) was the only large-scale application of this technique other than the Radambrazil mapping of the Amazon basin 1970/71; the demand was political as much as a development-oriented and the cost and technical difficulty determined that there was no repeat business.

Working with engineers

Over the years, HTS became synonymous with land resources surveys and overseas development. Much of the work was linked to projects undertaken by British civil engineers with HTS responsible for assessing land capability for irrigation or, as in Pakistan, the requirement for drainage. During the long-drawn-out negotiations to secure these projects, the expectations of both donors and recipients were well established; and working closely with the engineers meant that the precise needs for land resources information were well specified and the information was immediately put to use in design and construction. Sensitive management, respecting the positions of the clients and independent-minded field scientists, and a commercial mindset that delivered the goods, secured profitable follow-up work.

HTS adopted a concise and effective style of reporting including an executive summary and comprehensive technical appendices. The reports were well thumbed by officials and Ministers of the client governments, as well as by a later generation of technical staff. The Mahaweli power and irrigation project, in Sri Lanka, is an example. The foundations were laid by surveys in the 1950s and 60s (Hunting Survey Corporation 1962) which FAO followed up with a sketchy Master Plan envisaging 500MW hydro-power from several dams and 900 000 acres of irrigation over 30 years (FAO/UNDP 1969). In 1977, Huntings' reports were carefully studied by the Minister for Mahaweli Development in the new government, Gamini Dissanayaka, who won international backing for an Accelerated Plan with four major dams and 310 000 acres of irrigation – to be completed in six years! The British Ministry of Overseas Development contracted Sir Alexander Gibb and Partners and HTS to provide proposals and, ultimately, the final design and costing for the irrigation developments associated with the Victoria Dam: 21 000ha of field crops, a nucleus sugar estate of 4000ha, and settlement of 17 300 farmers on 1500 irrigated farms (Hunting Technical Services 1980/81).

Planning

The decade 1965-75 saw new thinking at the World Bank - focussing on planning, large-scale agricultural development schemes encompassing whole drainage basins, and sweeping changes in land administration and the institutions involved. HTS advised on all aspects of planning including urban, industrial, tourism, recreation and wildlife conservation; in-house capacity was expanded to include economics, sociology, forestry, farm mechanisation and fisheries. By 1978, the company was operating with 9 directors, 9 managerial and administrative staff, 17 in the laboratory, drawing office and reporting, and more than 60 project staff in the field; they also created a database that eventually encompassed more than 4000 independents who could be drawn upon.

An early example of planning was the 1964-6 Jenka Triangle Project in Malaya, in association with Tippets Abbot McCarthy Stratton, of New York (HTS and TAMS 1967). Huntings flew the photography, assessed groundwater prospects and was responsible 'for unravelling the mysteries of nearly 500 square miles of trackless jungle and, in a frighteningly short time of 18 months, translating them into an orderly integrated plan on which the livelihood of thousands of families and the fate of many millions of pounds will depend.'[26] Air-photo interpretation is not very helpful where land is covered by rainforest; the trees grow taller in the valleys and present an almost uniform canopy. Therefore soil survey was undertaken by a herringbone pattern of cuts through the forest with observations at regular intervals. The soil series

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[26] Dick Kettlewell, quoted by Thompson and others 2011

already established by the national soil survey were adopted as mapping units and translated into land suitability for oil palm and rubber, and land to be left under forest. Anthony Young, who worked on the survey, remarks: ‘The report… is admirably compact: the Outline Master Plan of only 60 pages, a thicker volume of text and a volume of maps’ (Young 2007). Twenty five years on, a World Bank impact evaluation study found 40 000ha of jungle cleared and 9 200 thriving families of smallholders settled on holdings of 4ha, conforming closely to the original plan: ‘The most important factors accounting for project success and sustainability of benefits have been project design, borrower support, adequate project organisation and a sound settlement system’ (IBRD 1987). That was development in those days - conservation of the rain forest wasn’t an issue.

From 1970 to 1990, HTS was involved in one of the largest planning exercises ever envisaged, the Transmigration Project in Indonesia. The aim was to increase the flow of migrants from overcrowded Java and Bali to the outer islands, then mostly under rainforest. Related aims included creating employment opportunities for the people coming onto the labour market, a higher standard of living for the landless, greater self-sufficiency, improved border security, and national integration – diverse objectives that gained more or less prominence as the economic and political climate changed. HTS worked on the selection of suitable land and, with the local and national governments, planning settlements. Some were successful: others failed, for various reasons. The lesson drawn was that resources survey was indispensible - but not enough to guarantee successful colonisation. The project was supported by the World Bank but controversy arose about how the migrants were selected, or coerced, where they were sent, and how the sites were selected; it became caught up in shifts of international development policy and, eventually, proved too unwieldy to maintain.

Environment and sustainable development

These policy shifts may be traced through three international conferences: the Stockholm Conference on the Human Environment, in 1972, which made a link between underdevelopment and environmental degradation; the 1980 Brandt Report which defined the growing North-South divide between rich and poor countries; and the Brundtland Report (WCED 1987) which argued that the future of the developed and least developed countries was linked and enunciated the principles of *sustainable development*. The new mantra attempted to square the circle (sustainability versus development) and maintained that the old approach of technical, single-issue solutions (soil conservation, for example) was failing.

It was harder to pin down what *was* needed but severe droughts in the Horn of Africa in the early 1970s and drought in the Sahel, Sudan and Ethiopia in the 1980s, seen on television screens across the world, brought political pressure for action. Rural development was still seen as important and the preferred approach became known as *integrated rural development*. This was taken up in HTS’s old stamping ground in Jebel Marra, continuing till 1995, and in a similar initiative in Southern Darfur from 1984 to 1988. Work extended from topographic mapping and resource surveys to regional development planning; moving on to small-scale irrigation developments and rain-fed cropping that were identified as most useful by local communities themselves, construction and maintenance of roads and wells, assistance to Rural Council education and health projects, and establishment of agricultural and community development services. This kind of work depends on long-term, dedicated technical support and winning the confidence of both government and local communities: but everything was at the mercy of famine that transformed the projects into emergency relief operations and the region’s slide into anarchy.

Monitoring and evaluation became an important theme in development projects in the 1990s. One of the largest and most innovative was part of the Flood Action Plan in Bangladesh, following the catastrophic floods in the late 1980s. Under contract to DFID, HTS led a consortium with a Bangladeshi private company, the Bangladesh Institute of Development Studies and the Japanese company Sanyu. Evaluation of the impacts of all flood control and irrigation projects in the country involved disciplines from fisheries to engineering to sociology. As well as conventional questionnaires, the project saw pioneering application of rapid rural appraisal techniques, drawing on the work of Robert Chambers at the Institute of Development Studies at the University of Sussex.

The end of an era

The Golden Age came to an end after about 1975. There was a loss of confidence in planning by governments and hikes in the oil price in 1973 and 1979 transferred money for development into petrodollars. Big projects depending on evaluation of natural resources dried up and HTS was a casualty. HTS had enjoyed the protection of the larger Huntings group to maintain facilities and full-time, pensionable staff during lean times but, in 1984, HTS finally closed its laboratories; the headquarters facilities at Elstree were sold in 1986 and the group relocated to Hemel Hempstead. The following year, Hunting Surveys, Hunting Geology and Geophysics and Hunting Surveys and Consultants closed. HTS, itself, was still busy; in 1988 the directorate numbered 11, headquarters managerial and administrative staff 21, and retained project staff about 60, but the stand-alone operation proved hard to maintain. Over the years, rivals had entered the scene - some were also associated with larger and more diverse business interests but many were free lances that did not carry permanent staff and costly facilities - and were able to quote lower prices; the clients were able to beat down the rate for the job. And, by the 1990s, the perceptions of development had changed again. The Washington Consensus on Development Aid focused on building local capacity and the capacity of national governments, themselves, to undertake the kind of work that HTS provided. Following the party line, instead of contracting British consultants or the Natural Resources Institute (NRI) to do development work, the British government started paying money directly to the treasuries of developing countries to do with it what they would (budget support).

Informal or formal training had been a component of HTS projects since the early resource surveys but one of the most effective methods is through technical assistance within an existing institution, such as a government department. During the 1980s, HTS provided experienced staff to local development and project authorities from Bhutan to Zambia in a management advisory role, in planning and operations, and in on-the-job training. For some years, HTC joined forces with Ian Macdonald and Associates offering short courses in the UK, often funded by the British Council; later, there was a link-up with the University of York - but these courses were time-consuming and detracted from the core business.

Various possibilities were considered to grow into areas linked to the original strength of the company but, in 1998, the Board opted for takeover by Genus plc, inheritor of the Milk Marketing Board. By chance, this coincided with DFID’s new strategy to reduce its dependence on quasi-governmental technical institutions like the NRI and Genus won contracts to manage DFID’s Natural Resources Systems Program and to support to the Rural Livelihoods Program. But this is not applied land resources information as we knew it: DFID seemed to lose interest in the technical side of development.

The Land Resources Development Centre

(After Makin, Bennet, Brunt and Griffin, 2006)

> *The objective of the Land Resources Division, later the Land Resources Development Centre, was to help and support developing countries to map, evaluate and develop their natural resources – a job for remarkable people. From 1956, they were part of the Directorate of Colonial Surveys, later the Directorate of Overseas Surveys; after 1971 they operated under the Overseas Development Administration. In 1987, they were merged with other units to create the Natural Resources Institute (NRI)and moved to the refurbished former HQ of the Royal Navy at Chatham. This imposed mighty overheads when the new mantra was competitiveness and, in 1996, NRI was privatised under the aegis of the University of Greenwich. Macdonald (1996) records: 'The Directorate was born of an idealism that was rooted in the responsibilities of Empire, and at a time when the ability of civil servants was rarely challenged. Its demise was the result of an arguably less idealistic allegiance to cutting the cost of government, and at a time when private enterprise was held to be paragon.'*

The end of Empire

Like Huntings, it all began with air photos. At the end of the Second World War, the British government set up the Directorate of Colonial Surveys to map the colonies: the RAF flew the photography, a team of surveyors established a trigonometric framework, and an army of draughtsmen interpreted the photos and married them with the survey framework. In 1953 the Directorate, now of Overseas Surveys (DOS) and based at Tolworth, in Surrey, obtained funds to assess the potential of air photos to provide information for opening up new lands. Martin Brunt was appointed as Land Use Officer in 1956 and, in the course of self-briefing tours across Africa, acquired an overflowing order book for land use surveys and assessments of development potential. In 1959, Brunt and his newly appointed assistant, Michael Bawden, were joined by two foresters who comprised the Commonwealth Forestry Air Survey Centre to become the Forestry and Land Use Division. As colonies lined up for independence, the Colonial Office realised that the new states would still need technical assistance. It was decided to amalgamate the DOS land use officers with the Colonial Pool of Soil Surveyors – hardy individuals skilled in air photo interpretation; the combined Land Resources Division, established in 1964, grew quickly in response to the demand for surveys and, in 1966, relocated from huts to the eighth floor of an incongruous tower block and was renamed the Land Resources Development Centre (LRDC).

In the first place, there had to be some kind of request from the host country but the service was free so there was no shortage of requests. Project proposals were generally written by LRDC staff themselves and, if agreed, funds were earmarked by the Desk Officer of the appropriate British government geographical department. Projects were reviewed at mid-term by the host government and British Ambassador or High Commissioner and, from the early 80s, also by an expert Liaison Group of senior LRDC staff.

<u>Land systems surveys</u>

In the beginning, the focus was natural resources assessment: soil survey, forest inventory and land capability. In 1960, Brunt and Bawden attended a Unesco conference on Natural Resources Management, in Toulouse, where Christian and Stewart of CSIRO explained their land systems surveys, which relied on stereoscopic interpretation of air photos to delineate land system boundaries and serve as a template for field observations. This became LRDC's standard approach, later supplemented by Landsat imagery, which avoided the need for painstaking compilation of air photo mosaics (one satellite image covered an area of 185km by 185km) but didn't provide the same resolution or three-dimensional perspective.

The early years saw surveys of tracts of land about which little was known; rapid appraisals taking just a few months, notably of NE Nigeria (Bawden and Tuley 1966) and Lesotho (Bawden and Carroll 1968). LRDC's expertise embraced geomorphology, soil survey and soil chemistry, agriculture, forestry, land use planning and, later, hydrology. Nominally, the field teams were integrated; geomorphologists interpreting the air photos worked with soil surveyors - but agriculturalists and foresters operated at a more detailed level and didn't always adopt the land systems framework. Early reports merely presented generalised field data for each land system, with an overview physical description drawing attention to development opportunities. But there was growing appreciation that knowledge of land resources was not enough for development: it was also important to understand farming systems and the constraints they faced. Charles Robertson was recruited as LRDC's first agricultural economist in 1970, sociologist Sean Conlin in 1976. Pitched in at the deep end, teams learned to appreciate each other's standpoint and often went beyond this - the agriculturalist endeavouring to collect precisely those data that he anticipated the sociologist would need. Land system reports became more detailed and were undertaken over several years: *e.g.* The Solomon Islands (Hansell and Wall 1974-7), northern Zambia (Mansfield and others 1975/6), central Nigeria (Wall and Hill 1978-82), and the whole of Indonesia (LRD 1985-89).

There was a stark contrast between the rates of completion of LRDC and commercial companies like HTS. However, LRDC could argue that, compared with a commercial company bound by contract to inflexible terms of reference, an LRDC team could recast its role to pursue potential development opportunities and the output might be only a short step away from a rural development feasibility study. Certainly, LRDC was able to apply a prodigious corporate memory and field teams experienced in multidisciplinary working whereas, increasingly, companies had to field scratch teams to suit changing market situations. Looking back, Makin and others (2006) record:

> *'The cost-effectiveness of land resources assessment was always a contentious issue on projects where there were no clearly stated objectives or precise terms of reference. What level of resources should be employed to gather what information in what level of detail? The more detailed investigations of the 70s adopted the view that land system surveys would be most useful if they were based on statistical concepts. Consequently, the land system survey of northern Zambia, which was intended to take a few months, was extended over several years. As land resources studies were seen to be "a good thing" in the 1970s, the appropriate resources were provided.'*

Integrated survey

The early surveys were unashamedly reconnaissance but later terms of reference implied that the host governments wanted to identify the entire range of opportunities for rural development. Development proposals should still be based on accurate representation of land resources so LRDC fielded multi-disciplinary teams - although final data from soil surveys, groundwater drilling and experimental sites inevitably arrived long after the economists had reached their conclusions. Examples of these early integrated surveys include Newalparasi, Nepal (Berry and others 1974), The Gambia Land Resources Study 1971-76 (Dunsmore and others 1976) and the Yemen Montane Plains and Wadi Rima (LRD Project Team 1977-8). The objectives in The Gambia, were: (1) integrated land resources study to include ecological survey, with special reference to the soils, and an analysis of population, land use and socio-economic factors; (2) enterprise studies with special reference to cotton, groundnuts, forage and integration of crops and livestock;(3) agricultural zoning, assessment of potential, and development plans - in particular to select areas suitable for double cropping of rice and cotton. Dalal-Clayton and Dent (2001) comment:

> *'LRD expended more than 20 man-years of effort, the greatest part of which was to establish soil series characterised by detailed laboratory data - only to publish the information as 1: 100 000 scale maps of soil*

associations that could have been completed in a tenth of the time. Subsequently, consultants to the Gambia Barrage Project found key data lacking for the soils of the tidal floodplain (which had resisted soil series classification) and no information on contours, river discharge, land use, or mangrove timber resources. A rapid appraisal that discovered 13 000ha of potential acid sulphate soils in the project area, and modelling, with approximate data, killed the Barrage Project in 3 man-months. These results were then confirmed by a further three man-years of conventional survey and laboratory analysis. LRDC surveys in the Gambia, classics of their kind, simultaneously achieved overkill of superfluous data and missed crucial information needed for development.'

This is not to belittle these surveys. The surveyors learned a lot and put down important scientific markers but development did not follow as a matter of course. There were straws in the wind from earlier LRDC projects[27] and later projects began with specific terms of reference relating to pre-defined development opportunities. But the cardinal issue of in-country capacity to make use of the information was glossed over until the last big LRDC survey in Indonesia in the 1980s.

A quarter century in Indonesia

LRDC's first mission in Indonesia, in 1975, was in response to a request from the Directorate of Transmigration to appraise land for settlement along the Trans-Sumatra Highway: first identifying, by remote sensing, areas worthy of further investigation; then semi-detailed ground investigation of land suitability involving 1:40 000-scale mapping of drainage, slopes, soils and current land use; assessment of development options – rubber, oil palm, food crops with and without irrigation; detailed agronomic and economic analysis; and, finally, physical planning of village sites (Hansell 1981). The World Bank funded the settlement of 30 000 families along the Highway, the LRDC project manager, Ian Hill, was seconded to the Bank to help evaluate physical plans for settlement, and LRDC was asked to support rapid development of 2.5million ha and settlement of half a million families under the Transmigration Planning Project, beginning in 1980. Most of the work was done by consultants; LRDC's involvement was a new departure - capacity building within the Jakarta Directorate of City and Regional Planning, and monitoring and evaluating the work of the consulting firms.

Early experience in choosing settlement sites - as much on the presence of blank areas on the map as on knowledge of the land - reaffirmed that settlement on unsuitable land can never succeed. In the context of the Ministry of Transmigration's target of settling 750 000 families over five years, LRDC's Regional Physical Planning Program for Transmigration (1984-90) responded to a request for help with the critical first stage of site selection For the first priority area, in Kalimantan, the four-man LRDC team had to devise a mapping procedure using 1:250 000 base maps derived from the newly available Landsat imagery. Cost, urgency and lack of reliable geological information dictated reconnaissance land system mapping from air photos and satellite imagery. This eliminated the rugged, forested interior and the coastal peat swamps and sand terraces, leaving the belt of lower hill country with development possibilities; fieldwork was confined to areas that were not easily-assessed by remote sensing. Three sets of maps were produced: land systems with an annotated legend that included suitability for a range of rain-fed crops, land use, and land status (showing areas already allocated in various government schemes including transmigration settlements.

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[27] Ivan Anderson, junior soil surveyor on *The Gambia Land Resource Study*, recounts his first job on arrival at the Department of Agriculture was clearing out thousands of copies of the fifty six 1:25 000 map sheets of the *Land Use of The Gambia* prepared by Martin Brunt - untouched in their DOS wrappers since 1959; '*Apparently, the Department of Agriculture staff didn't know what use to make of them. This is a recurring theme in all countries where I have worked – map skills are poorly developed and in many cases this is being exacerbated by the current prevalence and misuse of GIS technology.'*

The maps were well received and the team went on to map the rest of Kalimantan, Sumatra and Irian Jaya. At this time, it relocated to new facilities at the central mapping agency (BAKOSURTANAL) with access to Indonesian aerial photography, satellite imagery and new 1:50 000 topographic maps that greatly simplified map production, and a counterpart team that included two translators (all reports were translated into Indonesian). The final reconnaissance survey of Java, Lombok and Bali, in 1988/9, was politically delicate; the Ministry was initially reluctant but arguments for understanding the environmental background of the source areas of migrants and completing the first national environmental database won the day. The Inner Islands survey included demography and economic push-and-pull factors; it also introduced mapping of environmental hazards and recommended reforestation areas for degraded land.

The eight regional reviews (LRDC 1985/89) span the entire 1.9 million sq. km of Indonesia: 230 map sheets at scale 1:250 000 for each of the three series of maps. The number of land use types considered increased from the original seven to 27, and all information was rated according to its reliability. The total cost by 1990 was $4.6 million ($2.4/ha). The following year saw a National Overview report and coffee-table size atlas of maps at 1: 2.5million aimed at national planners (LRDC/BINA Program 1990). Most maps were simplifications of the regional maps but the geological, demographic and economic maps were entirely new; the overview included recommendations, a synopsis of methods and how to use the results, description of physical land resources, evaluation of development prospects, analysis of economic development trends, and concluding remarks on the main policy issues.

It was acknowledged that capacity to make good use of the maps and reports was limited, particularly at provincial and district level. Unusually, a two-year supplementary program was undertaken to disseminate the results and give guidance on how to use the information. The strategy was to train trainers and, so, create capacity that would survive the end of the project. Some 26 government and university staff contributed to 5-day workshops in every province and seminars in all the main land-using agencies at national level. A high proportion of senior staff attended the workshops, on ten occasions including the Provincial Governor or Deputy Governor. In parallel, a Map Improvement Component updated the land cover and land status maps - adding new roads, irrigation areas, land use categories, and administrative boundaries down to sub-district level; and the datasets for land systems, land suitability, recommended development areas, land use summaries and climate were completed. Finally, an LRDC soils expert was assigned to test the reliability of the land systems data in the field although, in the event, only a few representative areas were examined (Brinn 1993). Three of the four land systems tested did not conform even to the defining characteristics of landform, lithology or altitude – thanks to inaccurate original geological information; misidentification of landforms on air photos where the land surface was concealed by vegetation of uneven height and age, or where the pattern of landforms was too intricate to map at 1: 250 000; and from the difficulty of assessing the depth of peat from air photos. The disappointing results should have surprised no one; even the International Training Centre for Aerial Survey warned, long ago: 'it is evident that any attempt to map soils on photo-interpretation only is doomed to fail' (Vink 1961). It was demonstrated that land system mapping of tropical forest environments is feasible and cost-effective but full characterisation requires adequate fieldwork that was deemed inordinately expensive for most of the land use types considered.

Tropical soils analysis

Laboratory analysis has an equivocal reputation in resource assessment; it represents exactitude but it is hard to detect the contribution of these data to actual development. Working in places that had not been surveyed before, LRDC soil surveyors wanted laboratory data to support their field classifications and to establish chemical and physical properties. In-country facilities were non-existent or unreliable so, in the early days, samples were sent to the laboratories at Rothamsted. As the number of samples increased, LRDC set up its own Tropical Soils Analysis Unit (TSA) in 1967, at the National Agricultural Advisory

Service (NAAS) laboratories at Reading. The TSA received a wide range of soils and a typical analysis would scan 30 or more attributes. With few staff and little space, the new unit collaborated with NAAS to adapt conventional analytical methods to new equipment and procedures; automation and miniturisation facilitated the throughput of many more samples.

When extensive surveys became unfashionable and LRDC projects were given more defined objectives, the numbers of samples fell away. Laboratory costs were high, tighter deadlines required despatch of samples by air freight, and project budgets rarely included adequate funds for shipment and analysis of samples. At the same time, development policy shifted to supporting in-country capacity so TSA began to work with the British Council and ODA to give direct support to overseas laboratories, designing and commissioning new facilities, and providing technical training. However, at the time of the creation of the Natural Resources Institute, less than 200 samples a year were being processed by the laboratory and it was closed in 1994.

The end of the road

The surveys in Indonesia turned out to be LRDC's swan song. The 1979 general election brought in an administration bent on reducing the size and responsibilities of government and the status of overseas aid; and ODA swerved away from natural resources to social sciences. In 1984, the Department Overseas Survey was extinguished and the staff of LRDC halved to 45: no matter that the cuts coincided with famine in Ethiopia, crop failure across the Sahel, and growing public concern about environmental issues.

LRDC's situation was complicated by its merger in 1988 with the Tropical Development and Research Institute (TDRI)[28] to form the Overseas Development Natural Resources Institute, which became NRI in 1990 and was relocated to the expensively refurbished former Royal Navy HQ at Chatham. At a stroke, NRI was saddled with hugely increased overheads when, as an executive agency of ODA, it was expected to cover its costs by income. Perversely, release from government spending controls allowed a spurious increase in staff and, by 1992, LRDC had about 70 professional staff, more than half of them based overseas, but NRI's failure to meet its performance targets sounded its knell. In 1996, it was privatised under the aegis of the University of Greenwich, which already occupied part of the Chatham site.

The University expected that NRI would be profitable - based on predictions of likely income from the Department for International Development (DfID, successor to ODA). In the event, NRI's cost structure was uncompetitive; DfID shunned natural resources projects and international donors also shifted their attention to things like roads, water sanitation, health and education. Over four years within the University, NRI racked up £9.6 million of debt; 91 staff faced immediate redundancy in July 2001, including almost the entire Natural Resources Management Department, and a further 47 staff were axed in the same year. The name limps on.

[28] TDRI itself was formed by the amalgamation in the early 1980s of the Centre for Overseas Pest Research (COPR) and the Tropical Products Institute (TPI) – and was also managed by ODA.

ISRIC-World Soil Information

ISRIC was began life in Utrecht in 1971 as the World Soil Museum, receiving a modest subsidy from the Dutch Government under an agreement with Unesco. In 1975 it was relocated as the International Soil Reference and Information Centre to purpose-built premises in Wageningen, but was benevolently administered by the International Training Centre in Enschede until 2002 when ISRIC opted for Foundation status.

At this time, ISRIC found itself the sole international institute with a global mandate for land resources. The Soil Resources Conservation and Management Service of FAO had assumed this role during the Golden Age but the Soil Resources, Conservation and Management Service was progressively gutted and filleted and FAO no longer has any recognised soil resources specialist.

The International Board for Soil Research and Management (IBSRAM), brought to life by the Canadian, WO Bentley but established in Bangkok in 1985 did not undertake fundamental research on land resources but focussed on soil management networks of field experiments, *e.g.* networks for acid soils and for shrink-swell soils in Africa, and a network devoted to land management problems in Pacific island countries. The experiments were conducted within, and by scientists belonging to, the participating countries; IBSRAM provided advice and arranged coordination meetings and, also, tried to highlight some wider land resources issues. Its application for membership of CGIAR was rejected in 1990: CGIAR 'did not consider involvement in adaptive research and development activities of national programs to be a desirable evolutionary trend' in the system.[29] IBSRAM progressively lost international backing and was wound up in 1999.

The only other international soil and land research institute, the EU Joint Research Centre (JRC) at Ispra, in Italy, although scintillating, is strictly confined to European Community issues[30] so, in 2004, ISRIC assumed a wider mandate of advocacy, information and research: acting as anchorman in the continued development of the *World Reference Base for Soil Resources* (IUSS Working Group WRB 2006) and initiating several ground-breaking programs:

- *Global Assessment of Land Degradation and Improvement* under the FAO program Land Degradation in Drylands (Bai and others 2008, 2009)
- *Green Water Credits* - the creation of markets in water management services by farmers, supported by IFAD (Dent and Kauffman 2007)
- Acting as catalyst in the GEF *Global Carbon Benefits* program
- Two international digital soil mapping initiatives, the Gates-funded *GlobalSoilMap* and the EU FP7 *e-SOTER*.

But the will has since been lost and the institute has retracted into its founding role as a documentation centre. ISRIC became custodian of the scientific data of the 1:5 million scale FAO-Unesco *Soil map of the World* (1974-78) and, over the years, built up the World Soil Reference collection of fully analysed soil samples and an incomparable array of soil monoliths representing the mapping units of the world map, supported by the ISIS database of 950 soil profiles comprehensively analysed in-house. The *Soil Map of the World*, now available digitally, is still the only complete global coverage based on field survey; the latest *Harmonised World Soil Database* (Nachtergaele and others 2012), a 30 arc-second raster

[29] Report of a CGIAR meeting, Washington DC 1990, ch.9 quoted by Young (1998)
[30] But JRC seconded staff to FAO in 2012 to assist the launch of a Global Soil Partnership, a still unfunded network of national organisations and NGOs with concerns in land resources.

database combining updated regional and national soil data, still has large gaps filled by data from the *Soil Map of the World*.

Since 1989, ISRIC has been the World Data Centre for Soils – one of 50 centres that scrutinise and archive biophysical data and make them publicly available according to principles laid down by the International Council for Science (ICSU). Apart from the FAO-Unesco soil map, no one else archived any current soils data but, as and when funding could be secured, ISRIC has compiled existing soil surveys as soil and terrain (SOTER) databases at scales between 1:1million and 1:5million covering about half of the land surface, most recently for Central Africa (ISRIC 2007).

The library and map collection was brought back from the brink of extinction over the period 2003-2009. It comprises 15 000 documents, mainly hard-to-find *grey* literature of soil survey reports from developing countries, and 7 800 maps. The map collection was scanned in a joint venture with JRC and is available on-line and as DVDs as the *European Digital Archive of Soil Maps* (Selvaradjou and others 2005) though still lacking meta data. To date, one third of the documents have also been scanned.

ISRIC maintains the WISE database of scrutinized site and soil attribute data for 10 250 profiles from 149 countries - originally compiled for modelling climate change (Batjes 2009) and supplemented by a further, in-house set of 4 500 profiles. As a compilation of data from various soil surveys, there are inevitable taxonomic, geographic and soil-analytical gaps; there is no standard set of properties for which all profiles have analytical data; and the methods used vary over time and between surveys and laboratories - so results for the same property cannot be directly compared. Consequently, the data available for modelling are fewer than might be expected but adroit use of the data enables a wide range of environmental and agricultural applications at the continental scale (say 1:500 000). The current focus is on the *World Soil Information Service* – a centralised database to facilitate on-line access with one set of tools to all ISRIC data in a uniform format and to established international standards (Batjes and others 2011). Multilingual metadata are supplied on-line and there is partial global coverage of grid maps at 5.6 km resolution that permits querying, extraction and creation user-specified overlays and covariates; 1km-resolution grids are being added.

In 2011, ISRIC was again relocated, to the Wageningen University campus. The complement at this time was 12 scientists and 6 support staff with 6 scholars and guest researchers.

World Soil Survey Archive and Catalogue (WOSSAC)

Britain has a history of 175 years of systematic agricultural research and extension including 167 years of continuous field experiments at Rothamsted Experimental Station and more than a hundred years of systematic research in tropical agriculture beginning at Kew and the Imperial Institute (later incorporated within other organisations and, eventually, the Natural Resources Institute). Historical land resources survey data make up a significant legacy. After decades of neglect, the maps and reports from old surveys are increasingly valued for their scope and holistic interpretations of soil, rangeland and forests in their landscape, ecological and management contexts. Most of the Millennium Development Goals can be informed by these data, most specifically 'eradicating extreme poverty and hunger' and 'ensuring environmental sustainability'. For many countries, these are the only detailed studies of natural resources and their potential use. Their retention deserves serious attention, especially those in the grey literature of short print-runs and documents held in unstable countries.

In this context, WOSSAC was launched in 2004, as an initiative of the British Society of Soil Science, to maintain irreplaceable land resources reports and maps that were produced, mostly, by British surveyors, departments and companies in overseas territories. Its tasks are to collect and preserve overseas soil survey materials, and make them widely available by entering them into a contemporary land information system compliant with international standards for soil data, meta-data and data discovery, web services and reporting tools. The ultimate aim is to put the legacy data to good use in a broad range of environment and development applications (Hallet and others 2011). This will require development of ways to interrogate the data in any country, perhaps through Google Earth, and new communications technologies to transfer voluminous information to remote areas.

The archive is held at Cranfield University alongside the national soil-sample archive in a secure, dry, well-lit hall with industrial-scale roller shelving and large-format map cabinets. WOSSAC has acquired some 30 000 items, entirely by donation; the largest single acquisition has been the whole collection of the former Hunting Technical Services. Archiving and scanning a variety of media from map sheets and reports to air photos, satellite imagery on paper, film and in digital forms, photos, microfiche to electronic data has presented practical problems. Digital information held in obsolete media and data formats is impenetrable without special know-how and equipment. Paper records, on the other hand, are durable - although old records, often frayed, faded and with brittle bindings, need careful handling. To date, some 22 500 items have been catalogued and shelved; records from 293 territories and dating from 1909. Historically, the most prolific source period was 1960-1990. Bibliographic details of the archived items can be accessed on the web portal (http://www.wossac.com).

WOSSAC depends heavily on the brigade of pensioned-off scientists for material donations, cataloguing and maintenance; there has been no support from DfID, successor to the Ministry of Overseas Development that commissioned most of the original work, or from any other UK government source. Transfer of all the data to electronic format is a meticulous process that has to be externally funded - although a very modest outlay unlocks the value of relevant information that would, now, be very costly to gather - for instance, the recently completed scanning of the 2 300 archived documents on Sudan (for UNEP) and smaller projects for Tanzania (as an EU contribution to the African-European Georesources Observation System) and Jordan (for *GlobalSoilMap*). Archival information has been called upon for disaster relief, development planning and academic research – but nothing like enough and, even if preserved, it is becoming as unintelligible as Old English as the professional cadre that created it is pensioned off and the science is dropped from academic and technical curricula.

Without pretensions to comprehensive global coverage, WOSSAC does accept all international materials offered. However, its British bias means that WOSSAC should be considered as a member of a yet-to-be-established network of similar archives. An earlier proposal by ISRIC-World Soil Information to establish such a network ran into the sands of copyright (USDA), unwillingness to allow materials to leave the premises, even for digitising (FAO), and Cranfield's then policy of full-cost recovery that also stymied the use of the extensive output of the former Soil Survey of England and Wales, which Cranfield took under its wing, and the output of the former Soil Survey of Scotland held by the Hutton Institute (formerly the Macaulay Land Use Research Institute) in Aberdeen.

'And he gave it for his opinion that whoever could make two ears of corn or two blades of grass grow on a spot where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together.'

The King of Brobingnag in *Gulliver's Travels,* Jonathan Swift 1727

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Appendix 1: Diagnostic on land resources information

This diagnostic may be used as a framework for enquiries or round-table discussions to ascertain the status of land resources (LR) information in decision-making.. The main headings are over-arching issues; the bulleted questions provide a template of key issues on land resources information availability and use in planning and decision-making.

(A) Political context and participants

Does the political context encourage and enable, or inhibit, access to and use of knowledge of the land and LR information in policy-making, planning and decision-taking?

- Who has the strongest voice in policy debates that concern or influence sustainable land use and management and agricultural development?
- What checks and balances are in place to ensure that weaker voices can be heard?
  - What are the processes that encourage policy scrutiny?
  - Can the executive and legislature challenge policymaking processes?
  - Where is the real locus of power? How has decentralisation affected the relationships between knowledge and policymaking?
  - Is decision-making a technocratic process or are other voices encouraged in the debate? To what extent can those beyond the elite circle express their preferences in policy-making processes?
  - What are the opportunities for public debate in the media or other forums?
  - Is policy-making characterised by formal or informal relationships? Is participation based on personal patronage or broader social structures?
  - How do international agreements affect the issue being studied? How do they coincide or conflict with national priorities? What are the implications for the weighting of evidence from different sources?
  - During periods of political change, do policymakers have the resources to interact with a variety of knowledge providers? If not, what are the implications for the knowledge they draw on?
- How do the interests of the various players coincide or conflict?
- Are there strongly held values and belief systems which affect this?
- Who has credibility in policy debates?
  - How do the interests of the players determine whom is involved in a policy issue? What are the implications for weaker or fragmented voices?
  - How do personal interests affect what knowledge has priority in policy-making, and whether that knowledge is shared openly?
  - What effect do the interests of media organisations have on what they report, and how knowledge is translated to policy?
  - Is it clear how participants' values and beliefs (and by extension their values and ideologies) shape how coalitions are built around an issue?
  - Which participants are seen as credible experts on an issue? What does this mean for those who are excluded?

- Are there particular disciplines (technical, economic or social science) that are currently more credible than others in policy-making? What is the effect of this?

(B) Specific questions about LR information:

What kind of LR information is commonly or routinely used in policy-making, planning and development decisions in the country?

- Which types of NR knowledge/information are used in policy debates? Considering research knowledge, citizen knowledge and practical experience, is any one type dominant?
    - Is there a dominant narrative on agricultural development/intensification or environmental management? Are there particular kinds of knowledge or information that are strongly embedded in the policy-making and decision-making process and shape policy, planning and decisions?
    - Do central and local policy-making or planning processes use different types of knowledge/information? What dangers are associated with not recognising the differences?
    - What could be done to improve the supply and delivery of research-based knowledge to policy making? How could research communication be improved?
    - How could the delivery of citizen knowledge to policy be improved? How could citizens and interested parties be better linked to policymakers?
    - What are the main issues in improving the delivery of practice-informed knowledge (evaluations, project reports) to policymakers?
    - How do the skills, resources, organisational structures and processes within state agencies affect demand for NR knowledge/information?
- Are there any intermediaries – organisations or individuals – that work specifically across the interface between knowledge/information and policy/planning/decisions? How do they work and what effect do they have?
    - Which focus on *informing* : disseminating content, targeting decision-makers with information?
    - Which focus on *linking* : helping policy-makers and planners address a specific need by seeking out the necessary experts?
    - Which focus on *match-making* : helping policy-makers and planners think broadly about *e.g*. sustainable agricultural intensification?
    - Which focus on *engaging* : helping policy-makers and planners frame issues inclusively, contracting people to provide knowledge/information?
    - Which focus on *collaborating* : setting up joint agreements to work on particular policy issues?
    - Which focus on *building adaptive capacity* : building self-sustaining institutions able to deal with several issues simultaneously?

- How well are the various Government players able to source, interpret and use different forms of knowledge? Does this vary between the different branches (executive, legislature, judiciary)?
- Is there a formal or informal land use planning system?
- Do you consider that there is an adequate basis of LR facts on which to taking sound decisions on agriculture, the environment and development? Do decisions take account of the differences in soils and terrain, climate, hydrology, ecosystems, land use and management and the social and knowledge systems that underpin them?

- What drives or enables the use and consideration of LR information in planning and decision-making?
- If LR information is not used or little used, why is that? Are there particular challenges or constraining factors to the use of NR information in planning and decision-making?

What organisations in the country generate or supply LR information?
Institutional survey:

- Who is involved in generating LR information (*e.g*. statutory government institutions, research and survey organisations, NGOs, local consultants or national specialist organizations)?
- What do they do: *e.g.* collect and scrutinise data, undertake field surveys, *etc*. and for which specific topics?
- In what format is the information provided (*e.g.* reports, maps, databases, interpretation/support services)?
- How do you rate the quality/reliability of available LR information? Is it up-to-date?
- Does anyone monitor reliability and quality?
- Is LR information readily accessible and affordable? Is it understandable, and in a format that can be used by the decision makers who matter and whom may be non-specialists?
- Do you or others ever engage in dialogue with these organisations to discuss how the information they generate can better support policy-making, planning and development decisions; or what data are needed, at what scale, precision and format?

What is the level of capacity, skills, competence in generating, interpreting and advising on LR issues?

- Do the organisations identified above have enough trained and capable people to carry out their roles and responsibilities?
- Over the last few years, has capacity to generate NR information in the country increased or diminished (since when and how?)
    - Have some organisations closed or ceased effective operations?
    - Have others expanded their work or new ones been established?
- Are high-level academic or other training courses available in the country on LR management and on gathering/evaluating NR information? To what level (*e.g.* BSc) and in which specific fields, *e.g.* soils, forests, water, wildlife/biodiversity, geology.

(C) Questions about LR information specific to a particular case/initiative/decision

Was information concerning LR considered in planning or reaching decisions?

- If so, how?
- What is/was the key/priority LR information needed or used for decision-making?

What kinds of LR information were consulted or used?

- What particular kinds of LR information were considered?

- In what format was it provided (*e.g.* printed maps/reports/tabular data, electronic format, advice, written or verbal evidence *etc.*)
- Was it easily accessible?
- Was it understandable (to a non-specialist) and able to be used/interpreted?
- Did you engage LR specialists to interpret the information or advise of LR-related issues?

How was the LR information incorporated in the planning or decision-making process?

- At what stages? Was LR information considered at the concept or planning stage, or after key decisions had been taken?
- Were particular procedures or methods (*e.g.* land evaluation, land use planning, environmental impact assessment, strategic environmental assessment) used to assess or integrate such information?
- Were particular organisations or individuals specifically responsible for obtaining, reviewing, interpreting or advising on natural resources issues?
- How did this information inform or influence planning or decisions?
- Have there been unintended, unforeseen or unexpected outcomes (*e.g.* negative environmental or social impacts) of the policy, plan, project or initiative as a consequence of failure to take account of key LR information?
- Conversely, have there been positive outcomes of the initiative as a result of good planning based on adequate LR information?

Was LR information known to, or held by, local communities considered?

- How was this used in planning and reaching decisions?
- Were participatory methods of data collection, classification and analysis used ?
- If community-level surveys were undertaken, were the results explained to all interested parties, particularly local people, both for their information and for immediate correction of errors that are obvious with the benefit of local experience?

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Securing Land Resources: Information Needs Today and Tomorrow: State-of-the-Art Review

Sustainable use and management of land resources depends on good intelligence about their location, their condition and how this condition is changing. This review assesses the current status of land resources information, what information is used in land use policy, planning and management, and what information is actually needed. It also discusses some innovative methods and information systems that have matured during the past decade, including applications of digital elevation models, predictive ecosystem mapping, satellite imagery, airborne geophysics and land resource information systems.

The picture is uneven. The information wanted for exploitation of mineral and energy resources, smash-and-grab raids on forests, and the terrain and climate information needed by the military, aviation and shipping is better than ever. What has been neglected is fundamental information on renewable resources: soils, water and ecosystems, farming and pastoral systems, and their social context. Once-great institutions like FAO, the overseas survey agencies of the former colonial powers, and commercial companies that undertook major projects in land resources survey and development have been cut back or dismembered.

There are also contrasts country-wise: China and Brazil, have continued to improve their information and expertise; the Western World has privatised it; Eastern European countries in transition to market economies struggle to maintain capacity; and many poor countries that depended on technical assistance have given up. The reviews argues that we need to dig more deeply into the link between knowledge of the land and the ability to make good decisions about land use and management or, even, to see when a decision is needed but, on the world stage, the information needed for food and water security, adaptation to climate change and resilience against natural hazards is simply not there. For most of the world, the data we have are more than thirty years old and the capacity to interpret them has been pensioned off. The review concludes that there is an urgent need to put things right.

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