Meeting the need for land resources information in the 21st century – or not

David Dent and Barry Dalal-Clayton
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State-of-the-Art Review

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Sustainable use and management of the land depends on intelligence at the point of decision: information about the location of resources, their condition and how this condition is changing. In times of crisis, this has been appreciated at the highest level but, during the years of plenty, the attention of governments has been elsewhere. Today, information on natural resources is dispersed, fragmented, and used less and less.

The picture is uneven. Information needed for exploiting minerals, oil and gas, and the terrain and climate information required by the military, aviation and shipping is better than ever - these people know what they want and are prepared to pay for it. What has been neglected is fundamental knowledge of renewable resources: soils, water, forests, ecosystems, farming systems and their social context. This is no less important but the people whose livelihoods depend on it are not so well-off or so well organised and, though they may hold a wealth of local knowledge, this is hardly ever linked with formal land resources information. 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 a market economy struggle to maintain capacity; and many poor countries that depended on technical assistance have given up.

Here, we assess the current state of land resources information; what information is needed in land use policy, planning and management - and what is actually used. We have drawn on case studies and contributions by colleagues in the field which, we believe, represent current trends across the world. It is not our aim to describe in detail the tried-and-tested approaches to land use and development planning or the array of information and supporting tools that we have reviewed in earlier publications. However, we do highlight innovative methods that have come of age in recent years, including applications of digital elevation models, predictive ecosystem mapping, satellite imagery, airborne geophysics and land resource information systems.

We need to dig deeper 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 it is clear that food and water security and resilience against natural hazards and climate change will require a paradigm shift in land and water management. On the world stage, the information needed to do this is simply not there. Once-great institutions like FAO, the overseas survey agencies of former colonial powers, and commercial companies that undertook major surveys and development projects have been cut back or dismembered; most of our data are more than thirty years old and the capacity to interpret them is pensioned off. We consider why this is so and the options available to put things right.

David Dent and Barry Dalal-Clayton
Norwich and London, April 2014
ACKNOWLEDGEMENTS

We are grateful to the following colleagues and friends for insights, information and sections of text. However, none of them has had the opportunity to correct any misinterpretations, for which we accept responsibility.

Dick Arnold
Zhanguo Bai and Niels Batjes (ISRIC-World Soil Information, The Netherlands)
Michele Barson (Ministry of Agriculture Forestry and Fisheries, Australia)
Jonathan Davies (Global Drylands Initiative, IUCN, Kenya)
Partick Gicheru (National Agricultural Research Laboratories, Kenya)
Luc Gnacadja (formerly UNCCD)
Hubert George (FAO, Rome)
Geoffrey Howard (IUCN, Kenya)
Ruud Jansen (UNDP/UNEP Poverty-Environment Initiative, Botswana)
Inge-Marie Lorenzen Holst (consultant, Malaysia; formerly Danida, Indonesia)
Bob MacMillan (LandMapper Environmental Solutions Inc., Canada)
Neil Mackenzie (CSIRO, Australia)
Ajay Mathema (School of Environmental Management and Science, Nepal)
Freddy Nachtergaele (formerly FAO, Rome)
Athiannan Natrajan (ICAR, India)
Mike Norton-Griffiths (consultant, Kenya)
Lennart Olsson (Lund University School of Sustainability Studies, Sweden)
Colin Pain
Adam Pope (consultant, Zambia)
Bernie Powell (formerly Queensland Dept Natural Resources, Australia)
Thomas Reinsch (NRCS, Beltsville MD, USA)
Gemma Shepherd (UNEP, Kenya)
Sesekele Sokotela (Zambia Agricultural Research Institute)
Peter Tarr (Southern Africa Institute of Environmental Assessment)
Penny Urquart
Keith Valentine
Yunjin Wu (Institute of Soil Science, Chinese Academy of Sciences)
Anthony Young

We are further indebted to Hugh Brammer, Robert Brinkman, Amir Kassam and Andrew Bennett for constructive criticism of our earlier draft.
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EXECUTIVE SUMMARY

A perfect storm

The land provides 95 per cent of our food and clothing, all the timber bio-fuel and fresh water, and ecosystem services that underpin our economy and society – and it’s taken for granted. Between 1965 and 1980, the *green revolution* increased crop yields three-fold; for a generation, global food production outpaced population growth – and political attention turned elsewhere; but the revolution has stalled. 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; and double in developing countries.
- **We aren’t making any more land.** The area under cereals peaked in 1981, the total extent of arable in 1991, while the last quarter century has witnessed degradation of one quarter of the land surface and tracts of the best land are lost every day to urban development and infrastructure.
- **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 over-committed, and yields have levelled off - in some places they are declining.
- **Climate change** is likely to bring more-severe droughts, more-intense rains, and a rising sea level that threatens great cities and productive farmland.

A recent UK All-Party Parliamentary Inquiry 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 migration from poor countries to those better endowed - ‘A perfect storm’. And there are no charts: over the last 30 years, knowledge of the land and capacity to face up to land resources issues have atrophied – and that was before the global financial crisis.

The end of cheap food and fuel (Figure 1) has concentrated minds, once again, on food security.

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

![FAO Food Price Index](image)

*The real price index is the nominal price index deflated by the World Bank Manufacturers Unit Value Index (MIV)*
One response is the international land grab, where the power lies with the big players and which perpetuates farming systems that rely on more and more costly inputs. The sustainable alternative embraces minimum tillage, keeping the soil surface covered by crop residues, crop diversification, and adapting farm operations to every facet of the landscape. But this is high farming that demands greater knowledge of the land and better land resources information than has been marshalled up till now.

It’s not all the same out there

The need to factor natural resources information into development policy, planning and management seems obvious, yet it is happening less and less - even in countries like Australia and South Africa that depend overwhelmingly on land resources and are vulnerable to climate change. The hungry years after the Second World War were a Golden Age of land resources surveys. Demand for information came mainly from governments but the load they took upon themselves in attempting to direct the use of every field and hillside exceeded both the supply of information and their own ability to make use of it. Then, governments abdicated responsibility for land use and management, turned to markets to deliver their aims, and left land users to their own devices.

The applications of land resources information are by no means limited to food and water security. For example, the subsidence and heave of shrink-swell soils under alternating dry and wet conditions breaks up roads and buildings and snaps optic-fibre cables. Costs are orders of magnitude greater than the expense of the surveys needed to avoid problem areas in the first place and, in Australia, the telecom issue was flagged twenty years ago - but only now is there a scramble to map the offending soils.

We have been here many times before and decision-makers are always surprised that the information they need so urgently is not to hand. For a generation, we have seen:

- **Dismemberment of land resources institutions and atrophy of their data.** Across most of the world, the knowledge needed to secure food and water resources, mitigate natural hazards and adapt to climate change is not there anymore. The information we do have is more than thirty years old, dispersed, fragmented and, sometimes, maintained in an amazingly amateur way.

- **Erosion of specialist skills within natural resources agencies and universities.** Across the western world, the cadre of specialists has been pensioned off and universities and colleges no longer offer training in land resources survey and land use planning.

Well-informed decision making requires, first, up-to-date coverage of primary data at a scale matching the decision in hand, preferably in electronic format accessible through the internet and compatible with climatic data, digital terrain models and economic models; secondly, a cadre of experts charged with selecting relevant data and translating them into directly usable advice; and thirdly, effective demand from decision makers. Knock away any one of the three legs and the others will also fall. We are where we are because the demand for land resources information ebbed away; outside of China, Brazil, the USA and maybe India, no one is collecting and maintaining the information.

How to put things right?

Shouting at decision-makers, telling them that they are doing a bad job or getting it wrong, doesn’t help. Without a strong pull in the shape of demand for natural resources information, trying from the outside to introduce different ways of doing things (the push agenda) is fruitless: far better to secure a pull by
dialogue with decision-makers, seeking to understand their needs and concerns, and explaining how our own ideas and information might help.

Without returning to command-and-control, there are strong arguments for formal land resources policies and framework legislation. In Europe, the 2006 Soil Thematic Strategy, which received common assent, called for a comprehensive approach to preserve *soil functions* through:

- **Awareness raising and education** to create broad ownership of land resources issues;
- **Research** to understand the problems and find solutions. We also need to find practical ways of uniting local knowledge and formal information, and linking land evaluation with action on the ground;
- **Integration of soil protection with other policies**. Under the Common Agricultural Policy, payments are withheld if minimum standards of husbandry are not met - but the bar is set well short of sustainability;
- **Legislation: a Soils Directive** - which was not adopted by the Council of Ministers. The alternative might be payment for environmental services but buyers will only pay for what can be measured - which means reliable, up-to-date information on the status and change of the specified resource or hazard. This information is hard to get.

Governments, companies and communities need intelligence to determine the dimensions of policy and management issues, assess whether the information to hand is good enough, and specify what more is required. It will need a sea change in the policies of national governments to re-instate professional land resources survey at the field scale needed for precision farming and community action but there are other paths that might be followed. For instance, something like the British Geological Survey’s *mySoil* app can provide users of smart-phones with an interactive map of land resources and the facility to build up their own information within and compatible with formal knowledge. Privately commissioned surveys for big-farm precision agriculture already operate like this but the new information will soon be lost unless there is a requirement to archive it with a public institution responsible for maintenance and access to the data - several countries manage mineral resources information in this way.

Facts don’t speak for themselves: someone has to speak up for them - information itself has need of champions. But once government and industry appreciate what they need, roles may be assigned to institutions with related expertise that can broker information, specify what more may be required and build up their capacity to provide it. The dearth of experienced staff will be a bottleneck that must be rectified as a matter of urgency.

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, the ongoing cost will be no more than is spent today by Premier League football club or a middling university but the time horizon is a generation. The Chinese and Brazilians are already well on the way.

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

Oscar Wilde
Chapter 1

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

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. And we need natural forests, wetlands and rangelands that maintain ecosystem services like regulation of the water and carbon cycles, disposal of wastes and renewal of soil fertility (Daly and others 1997). These services are irreplaceable – and taken for granted. 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). Several colliding issues are putting policy makers under pressure:

1.1.1 Burgeoning demand

The world now supports more than three times as many people as it did at the outbreak of the First World War and the population is projected to increase from 7 billion today to 9.3 billion by 2050 (UN 2011). Compared with 2009, demand for food is likely to surge by 70 per cent globally and 100 per cent in developing countries (FAO 2011). The issue is not just the growing human population but also increasing wealth that supports demand for meat, so more and more grain is diverted to stock feed. Moreover, significant areas are being turned over to the production of bio-fuel.

1.1.2 Finite land resources

This production has to come from the same land resources or, if present trends continue, much less. 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 area under irrigation doubled, increasing total cropland by 12 per cent, but 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 in 1987, the total extent of arable peaked around 1991 (Figure 3) and can hardly be extended except for limited areas in South America and sub-Saharan Africa (Lambin and others 2013).

1.1.3 Land degradation

On top of historical land degradation going back 10000 years in long-settled areas, the last quarter century has witnessed degradation of one quarter of the land surface; one quarter of the arable and one third of forests. Figure 4 depicts this trend in terms of declining net primary productivity (NPP – the energy
**Figure 2: Changes in the cropped area (FAOSTAT 2010)**

![Diagram showing changes in the cropped area](image)

*Source: FAO (2010b)*

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

![Diagram showing world population, cultivation and meat production](image)
remaining in the ecosystem after respiration and stored as biomass). Africa south of the equator, SE Asia and south China have been 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 outright destruction of vegetation and the soil itself, insidious aspects of land degradation include intensification of soil acidity, salinity and sodicity, and loss of humus, soil structure and biodiversity. NDVI data show that heavy use of fertilizer across much of China, the Indo-Gangetic Plain, Europe, the American mid-West and southern Brazil is no longer accompanied by increasing production (Potter and others 2010, MacDonald and others 2011) but NDVI trends almost certainly underestimate the problem; farming everywhere is running down stocks of soil organic matter that supplies plant nutrients, maintains infiltration, available water capacity and resilience against erosion, and fuels soil biodiversity. Production may be maintained until a tipping point is reached then the system flips – like the

1 Lal (2004) estimates 82 per cent of terrestrial carbon is soil organic matter. In temperate regions, soil loses 30-50 per cent of organic matter within 50 years of cultivation; in the tropics, 10 years. In the last century, 60 percent of soil and biomass carbon has been lost through land use change and the current loss of about 1.5 billion tons/year is a significant proportion of greenhouse gas emissions; the best soils in the world, the chernozem, have lost 30-40 per cent of their organic carbon (c40 tonnes/ha) and under bare fallow losses are 80 tonnes/ha in 50 years – yet they yield abundantly till they reach their tipping point (Krupenikov and others 2011). The more recent exploitation of tropical peatlands to produce rice or bio-fuel, also runs up a big soil carbon debt (Fargione and others 2008).
Dust Bowl in the USA in the 1930s, when the black earth turned to dust. This is still happening; one of us witnessed seven million tons of topsoil whipped up from parched farmland in Queensland and New South Wales (Australian 2002) and, 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 as far away as Kent (Brimli 2008).

The food system is unsustainable. Current farming systems are driving land degradation - not to mention social inequity; fuel and fertilizer are no longer cheap; water resources are over-allocated in all the main food-producing areas; and the yield increases of the green revolution have tailed off - in some places they are decreasing. Yields and factor productivities of field crops in Europe have been decreasing over the past 20-25 years (Boincean and Kassam 2014). 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).

1.1.4 Climate change

Sustainability must be achieved while coping with climate change. There is great uncertainty about the absolute values predicted by global climatic models but median predictions to 2030/50 indicate a reduction in the growing season of more than 5 per cent across a swath of the global tropics - critically the growing season is cut to less than 120 days in Mexico, NE Brazil, southern and W Africa and the Indo-Gangetic Plain (Ericksen and others 2011). Global crop yields are predicted to fall by 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). Severely affected places include Australia, where 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); and South Asia where IFPRI projects a 44 per cent drop in wheat yields by 2050 in the absence of effective mitigation measures. Half of India’s high-potential wheat producing area is likely to become heat-stressed, short-growing-season cropland and, for every degree Celsius rise in mean temperature, wheat yields are likely to fall by 6 million tonnes/year; a loss of $1.3 billion/year at current prices (Swaminathan 2011).

1.2 Policy failure and market failure

Global security depends on food and water security - yet land resources are the policy-makers’ blind spot. Environmental services underpin our economy and society but don’t enter the economic reckoning; loss of natural capital isn’t accounted in the price of production. When farmers and loggers repeat the cycle of degrade > abandon > migrate, the legacy of dust clouds, landslides, choked reservoirs and stream channels, and greenhouse-gas emissions is handed on to future generations. 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 action to meet these needs without compromising the capacity of future generations to meet their needs (WCED 1987). Sustainable development means conservation combined with production but public concern has focussed on pollution and nature conservation rather than on land as a productive resource. In the face of disinvestment in agriculture, development assistance and
knowledge of the land, a procession of initiatives (the International Board for Soil Research and Management, the CGIAR Challenge Program on Water and Food, EU Soil Protection Policy, the Millennium Goals, and the Millennium Ecosystem Assessment) has left no tangible legacy on the ground.

The food price spike of 2007/8 and subsequent price volatility has concentrated minds, once again, on food security (Royal Society 2009, Beddington 2010). The UK All-Party Parliamentary Inquiry into Global Food Security (APPG 2010) predicted ‘a perfect storm of global events’ from collision of burgeoning 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 where they 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 to action embrace land use planning, spread of best practice, innovation, and capacity building (e.g. NEPAD 2010, Montpellier Panel 2010, FAO 2011, UN CST 2012).

1.3 A very present need

Food and water security and adaptation to climate change require more productive, sustainable, climate-smart land and water management. Two candidates have proven adaptable to local ecosystems, cultures and market demand:

- **Conservation agriculture**: embracing minimum or no-till, maintaining ground cover with a mulch of crop residues, and diversification of crops grown in rotation or association. In concert, these practices build resilience by protecting the surface from driving rain, wind and baking sun; put back organic matter into the soil, stabilise soil structure, increase infiltration and cut destructive runoff; control weeds and pests; and increase crop yields while substantially cutting the use of fossil fuels (Kassam and others 2009, 2011; Krupenkov and others 2011; FAO 2013). The System of Rice Intensification (SRI) also multiplies yields from conventional management using much lower seed rates and less water by creating soil conditions conducive to crop roots and the biota that mobilise the natural store of nutrients (Kassam, Stoop & Uphoff 2011). All elements of sustainability benefit from good water management, locally adapted seeds, and integrated management of pests, weeds and diseases - commercial farmers may still use herbicides to control weeds but crop rotation and mulching also help.

- **Precision farming**: adapting farm operations to every facet of the landscape, taking advantage of natural variation - rather than ignoring it and compensating with brute force and blanket application of agro-chemicals. The idea of applying the right inputs at the right time at the right place in the field emerged in the USA some thirty years ago (Robert and others 1995); modern variants include computer-controlled application of fertilizer, pesticides and irrigation (Chen and others 2011) but the principle is equally applicable to smallholder (Kienze 2013).

This is *high farming* that demands equally high knowledge of the land. Movers and shakers assert that the science and information are to hand: not so. Knowledge of the land built up during the Golden Age of land resources surveys from 1945 to 1975 made the green revolution possible but, when the going was good, political attention turned elsewhere; the knowledge infrastructure was neglected; and the legacy data are being lost along with the expertise needed to interpret them. 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, most of our information is more than thirty years old and was collected for different purposes and with different assumptions from today’s.
Generations of trial and error may have shown farmers where the best land lies and which crops, varieties and cultivation practices are best adapted to every plot. As Robert Brinkman points out:

‘The actual users of their natural resources make all the difference – whether sustainable resource husbandry and environmental protection or degradation and impoverishment. Even without systematic and detailed resources information, much can be done on the ground with land and water users and, if done with their participation, can take on a viral life of its own, gradually expanding from village to village, and through farmers’ field schools.’

This is how conservation agriculture has been adopted across some 125 million ha and it is expanding at 6-8 million ha/year (Friedrich and others 2012, Friedrich 2013) but farmers are having to learn from their mistakes; faster uptake with fewer costly mistakes needs sustained policy and institutional support (Pretty and others 2011). And just as with the green revolution, all the benefits of high farming can be reaped only with scientific information that goes beyond local knowledge. A new thrust of applied research is needed to acquire better land resources information and better ways of bringing it to decision makers. Some recent, prominent reports highlight the need to rebuild both 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 knowledge of the land and the cadre of specialists; and the Foresight report (Box 1) called for improvement of the evidence base upon which decisions are made and progress measured.

### Box1: 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’. 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.’

In the international arena, FAO (2011) identified three areas where much greater investment is needed to achieve 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 one champions the knowledge itself.²

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²Out 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.’ 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.’ 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.’
1.4 As the decision makers see it

Knowledge may play many parts – anchoring policy in an understanding of the world and challenging policy-makers to think more broadly about what might be achieved. But access to information is not enough; even taking the optimistic view that decision makers understand what is presented to them, they have to balance a wide range of interests and are subject to many influences. And knowledge is not value-neutral; much is contested; different groups attach different weights to it and some knowledge providers carry more weight than others. An NGO would be more likely to listen to farmers’ concerns about environmental impacts of agribusiness than to representatives of the business itself; proponents of off-beat initiatives like SRI and conservation agriculture are blackballed by established scientific journals; and our Australian case study illustrates how beleaguered scientists in the States and Territories don’t take kindly to new-fangled ideas from Canberra.

Jones and others (2012) have elaborated four factors that determine how 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?)

- 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?)
Chapter 2

LAND RESOURCES INFORMATION

2.1 A short history

Systematic information on natural resources dates from the Age of Empire but, in the aftermath of 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 ebbed 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 Pamplemousse in Mauritius, dates from 1735. The founding of the royal gardens in Kew, in 1759, began a prolific period of applied research; colonial powers established chains of tropical gardens and 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 dominions.

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. The impact of science and planning was limited 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: a commercial farming sector (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 suitable land for settlement and plantations. Information was also needed to deal with soil erosion, to identify areas free from tsetse fly, and set aside forest reserves. At that time, there was scant 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; 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 was adopted by later integrated surveys. The earliest and some of the best examples were the vegetation and soil surveys of Northern Rhodesia (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, soil surveys became a national priority in the USA. 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) secured the methodology and, over thirty years, completion of a detailed survey of the whole country. Soil Types were mapped according to the texture of the topsoil and grouped into Soil Series according to the parent material following Whitney (1909) but mapped through new eyes following Marbut’s appreciation of the Russian school of pedology (Marbut 1935). The genius of the American method lies in the naming of series according to the locality where they are first mapped – for instance Miami Series. Soil Series are real and local place names come easily to the tongue so people can relate to them. The soil surveyor, extension service and other map users use the series to carry information about different soils and their behaviour; and the series name remains sacrosanct whatever arcane changes may be made to higher-order classifications.

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 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 forest conservation, the Dept of Agriculture on land suitable for farming, and the Irrigation Dept 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

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3Russian concepts about the distinctive sequence of layers in the soil profile and their relationships with the landscape arrived through Glinka’s 1905 text, translated into German in 1914 and, subsequently by Curtis Marbut into English (1927). Much later, they were snappily expressed by Jenny (1941) as The factors of soil formation.
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 112). Another despatch to colonial administrations in 1945 required preparation of development plans and drew attention to the need for a proper balance between development and welfare. Plans were made to undertake topographic and geological surveys throughout the colonies, supported by RAF aerial photography.

2.1.2 The Golden Age

‘There occurred (recurred I should say because it happened in 1914 too) overnight after the declaration of war, a reversal of the official indifference to the state of the soil or the solvency of farmers... Never again must agriculture be allowed to suffer from neglect; never again must the nation forget what it owes to its farmers. I do not suggest that the propaganda was insincere; it was deeply felt at the time. We were fighting for our own land.’

Foreword to new edition of *Apple Acre* (first published in 1942), Adrian Bell 1962

The aftermath of the Second World War included an urgent demand for surveys. There were big blank spaces on the maps to be filled and the spectacular failure of the Tanganyika Groundnut Scheme (Box 3) became a touchstone for land resources surveys worldwide. The simple conclusion that any development located on unsuitable land can never succeed guaranteed the position of land resources surveys for a generation – and has been reinforced time and time again. The objectives of surveys were expressed by Ernest Chenery’s 1954 proposal for a soil, vegetation and agricultural survey of Uganda: ‘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’ (quoted by Young 2007). But scientists were kept firmly in their place. The introduction to the report of the Dept of Soil and Land Use Survey of the Gold Coast 1951-55 states: ‘It will be observed that...the Department’s work is purely advisory, being based on surveys in the field, analyses in the laboratory, and up-to-date information on what has proved successful in other parts of the tropics where similar conditions prevail. The Department is not responsible for experimental trial of its recommendations nor for their demonstration on a wider scale.’

Surveys followed one of two tracks. The first was the American model of detailed field survey and laboratory analysis with the *Soil Series* as the mapping unit (Kellogg 1937, Soil Survey Staff 1952); it was accepted that information is needed at the field scale for layout of irrigation schemes and for agricultural improvement in thickly settled countries. 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 Stewart1951). Land systems survey depends on presumed correlations of 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.
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 farm machinery could be procured. After nine weeks in the field, the investigators recommended mechanised clearance of 3.3 million acres over six years on farms of 30 000 acres to secure an annual production of 600 000 tons of groundnuts.

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 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 (Nachingwea); 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.’ The machinery was second-hand: bulldozers from American army surplus and Canadian tractors. Bush clearing began in April but machines broke down, it was hard to extract the long roots of the native vegetation, ploughs were blunted by the abrasive soil which was rendered unsuitable for groundnuts through compaction, and 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.’ Anthony 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 £36 million; 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. Nachingwea remained under large-scale, mechanized production of soya, groundnuts, maize and cashew but was, eventually, abandoned.

After Dalal-Clayton & Dent 2001

Another premise is that most land uses are constrained by the combined 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 Landsat1, 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 (rule out 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 appended an overview that drew attention to development opportunities and constraints, e.g. land systems atlases of Lesotho (Bawden and Carroll 1968), Uganda (Ollier and others 1969), Swaziland (Murdoch and others 1971). Later surveys in Nigeria culminated in seven substantial volumes 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 engineers building the infrastructure, land resources surveys made a big contribution. The Jengka Triangle in Malaya (Box 4) and the Mahawelli power and irrigation project in Sri Lanka (HTS 1980/81) count as success stories. On the other hand, the Blue Nile Spinning and Weaving Company was established in the Sudan, in 1975, on the black cracking clays of the Gezira - even though FAO soil scientists on the spot pointed out what these soils do to buildings; the plant was built anyway but abandoned almost immediately when the floors reared up and the machines were unable to operate (Freddy Nachtergaele, personal communication).

**Box 4: The Jengka Triangle**

The decade 1965-75 saw new thinking at the World Bank - focussing on planning, big development schemes encompassing whole drainage basins, and sweeping changes in land administration and institutions. An early example was the 1964-6 Jengka Triangle Project in Malaya, undertaken by Hunting Technical Services in association with Tippets Abbot McCarthy Stratton, of New York (HTS and TAMS 1967). Hunting 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.’ (Dick Kettlewell, quoted by Thompson and others 2011). 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 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 evaluation study found 40 000ha of jungle cleared and 9 200 thriving smallholder families 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.

Strong support for land resources surveys came from specialist agencies of the UN, notably FAO which, itself, had 300 surveyors in the field in the 1970s and operated an ‘associate experts’ scheme to blood young professionals. This period also saw proliferation of international aid agencies; some like the Land Resources Division of the UK Directorate of Overseas Surveys evolved from the colonial administration, 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 (Box 6). 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 there was a growing appreciation that land evaluation was not enough: it was also important to understand the constraints faced by farming systems. So increasingly complex, integrated surveys were undertaken by 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 society. But governance and the critical issue of local capacity to marshal, understand and act upon the information were tough subjects in newly independent countries.

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 places suited to the new technology, carried global food production ahead of the population curve (Pinstrup-Andersen and others 1999). Amid the social and political uncertainties of the 1970s and 1980s, the early success of the package allowed political attention to drift away from natural resources. The new technology appeared to transcend differences in soil and climate; it seemed that any deficiency of the soil could be rectified with fertilizer; any deficiency of management by a battery of agrochemicals.

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 intractable; 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. The 1972 Stockholm Conference on the Human Environment made a link between underdevelopment and environmental degradation; and an environmental movement gathered momentum – though without much understanding of the resources under threat. The Brundtland Report, in 1980, defined the North-South divide and the widening gap between rich and poor countries. Finally, in an attempt to square the circle of poverty, land degradation and under-development, the Brundtland Report (WCED1987) came up with the mantra *sustainable development*.

Drought in the Sahel in the late 1960s and early ‘70s, and again 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. First, siren voices called for integrated rural development programs (IRDPs) – mutually supportive combinations of improved agronomic practices, credit, new roads and water supply, sometimes clarification of land tenure; a baseline survey of natural resources was often part of the package. These ideas are now embedded in the philosophy of sustainable development but most IRDPs founders on weak institutional capacity. There were successes (e.g. Mellors 1988) but many programs were shopping lists of essentially separate projects 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. IRDPs depended on donor funding; they may have intended to work with local institutions but they were implemented through autonomous project bodies and came to rely on this autonomy to achieve their objectives. In several cases known to us, all activity ceased when external funding was withdrawn - they sank without a ripple.

Thanks to the application of science and technology in industrialised countries and in populous developing countries where conditions were favourable, the world had never been so rich or so well fed. Even so, what
Gleave (1987) called the ‘the big push’- large projects dependent on transfer of technology from the developed world - was found wanting; often unsound because of false assumptions and lack of local knowledge; often unwanted 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. 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 dried up; institutions were run down; and the residual natural resources budget was diverted to the social sciences - participatory planning, indigenous knowledge, equitable access to resources, institutional coordination and governance.

To some extent, attention was 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. The announcement of the World Conservation Strategy (IUCN/WWF/UNEP 1980) was followed by spurious activity under the umbrella of National Conservation Strategies and, in the same vein, 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 catastrophic flooding in 1987 and 1988 prompted the Bangladesh Flood Action Plan; this was launched as a series of regional studies to identify appropriate action but what emerged focused on flood control, didn’t 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 such 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 used essentially the same set of old, inaccurate or suspect data, which did nothing for the quality of decision-making (Dalal-Clayton and Dent 2001).

Agenda 21, one of the accords of the Rio Conference on Environment and Development (UNCED 1992), urged countries to develop national strategies for sustainable development. The conference also spawned the UN Convention on Biological Diversity, the UN Framework Convention on Climate Change, and the UN Convention to Combat Desertification (UNCCD). The first of these has maintained the international profile of biodiversity. The second, briefly, transformed the global agenda through the activities of Intergovernmental Panel on Climate Change. But UNCCD, embracing land degradation and sustainable land management, was allotted negligible resources and has achieved negligible results on the ground. It failed to achieve credibility on two counts: oversimplification of evidence and of the solutions proposed – for instance the groundless extrapolation of local observations of the shifting margin of the Sahara (Lamprey 1988); 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 satellite measurements (see Section 3.4.3) there had never been any measurements of land degradation beyond the experimental plot – estimates were extrapolations, usually employing the so-called Universal Soil Loss Equation that predicts soil erosion according to the erosive force of the rainfall, the amount of ground cover, and soil attributes (Wischmeier and Smith 1978). No matter that there were no good data for some (or any) of these factors, estimates were made (e.g. Brown and Wolf 1984, Pimental and others 1995) - and easily debunked (Crosson 1995, 2003).

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4One of us recalls the response of Prime Minister Thatcher to a presentation by the Soil Survey of England and Wales: ‘If your information is really as useful as you tell me it is, then people will pay for it.’ Government funding for the soil survey was withdrawn forthwith but Cranfield University took the Prime Minister at her word and took the soil survey under its wing. Henceforth, this information, which had already been paid for by taxpayers, was available only on further payment – but hardly anyone did pay for it.
The Millennium Development Goals (MDGs), adopted in 2000, attempted to focus the development agenda with specific targets to be achieved by 2015\(^5\). In 2002, the Johannesburg World Summit on Sustainable Development (WSSD) made a commitment to ‘protecting and managing the natural resource base of economic and social development’ so as to reverse land degradation ‘as soon as 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. Most recently, the UN Conference on Sustainable Development in Rio de Janeiro in 2012 (Rio+20), intended to renew political commitment, merely took note of ongoing activities and continuing challenges and barely acknowledged the role of land resources information.

The Age of Uncertainty was marked by spasms of uncritical thinking. Oversimplification of the situation on the ground continued unchecked by hard data. To some degree, this oversimplification may be explained by a sense of urgency: the urgency is real but does not encourage attention to complexity. For instance, in 1974, the Secretary General of the UN declared: ‘In less than 50 years time … the advancing desert threatens to wipe three or four countries of Africa off the map’ (Brabyn 1975) - they are still on the map and greener now than they were then. 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 by the scientific community.

2.2 Where are we now?

2.2.1 Ebbing demand for land resources information

Information reduces the risks in decision-making. To avoid costly mistakes, and because people’s lives and livelihoods depend on it, land use policy planning and management should be based on the best available knowledge. First, decision makers must be aware that natural resources are a key consideration; then they need up-to-date, trustworthy information and the expertise to interpret it for the task in hand. The Golden Age was marked by demand for just such information at the highest level. This demand was satisfied by government agencies and private companies that developed effective methods for all kinds of land resources surveys and procedures to translate these data in terms of land use potential. But the tide of demand went out as quickly as it came in, before many countries had achieved national coverage. By and large, governments are no longer seeking this information: they have abdicated responsibility for food and agriculture and the environment. Over the last thirty years, policy has been market-led, rather than seeking to support strategic fields of knowledge; many countries have seen a dramatic decline in the marshalling of fundamental land resources information, the dismemberment of public and private institutions in the field and, consequently, attrition of the cadre of experts. This applies to not only food and agriculture but, also, the environment - even climate change where it has proved hard to secure meaningful action.

Payment for environmental services is a market-related alternative. Carbon trading started under the Kyoto Protocol - but it remains 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 have been researched in several countries (Dent and Kauffman 2007) but not yet implemented anywhere. Hard-nosed investors will only pay for what can be measured so any such mechanism depends on reliable, up-to-date information on the status and change of the specified resource or hazard – and this information is hard to get.

Information has been privatised. On one hand, ever-greater demand from the military, civil aviation and shipping for better information on terrain, weather and climate, and a cyclical demand for minerals prospecting have enabled topographic and geological surveys, meteorological services and their private counterparts to build 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 (Box 5), which are exploited by fragmented and not-very-profitable enterprises.

Box 5. Putting salt on the map in Australia

The explorer Charles Sturt encountered the dry bed of the Darling River on February 6th 1829:

’on closer examination, we discovered some springs in the very bed of the river, from which a considerable stream was gushing, and from the incrustation around them, we had no difficulty in guessing their nature: in fact they were brine springs’ (Sturt 1833).

When he came across the lower reaches of the river in the following year, it was in spate.

In the driest continent, salt a fact of life; lakes and groundwater are mostly brackish and salt-affected soils occupy more of Australia than any other country. Salinity is salt in the wrong place and generalisation of rather few local observations suggested that clearance of the uplands, replacing the bush by crops and pastures that used less water, was leaching salt into the valleys that carry irrigated crops and nearly all urban development and infrastructure. The Australian dryland salinity assessment 2000 (NLWRA 2001) estimated that 5.7million ha was affected and by 2025 the area could increase to 17million ha, afflicting 200 towns, 52 000km of roads and 20 000km of streams. If salinity could be arrested only by reversion of most Australian farmland to bush, then this was a problem too.

But in just a few months, political and scientific leadership at the Commonwealth level and technical advances in airborne geophysics transformed understanding of salinity. Airborne electromagnetics (AEM) measures ground conductivity; by calibration against borehole data, this translates to a 3-dimensional map of the salt stores to a depth of 100m. Airborne magnetics measures natural magnetism, revealing geological structure and picking out, with yard-perfect precision, paleo-channels that transport water and salt. Knowing where the salt is, the conduits through which it moves, and the rate of delivery (from field measurements of transmissivity), surgical intervention becomes feasible. Encouraged by the success of pilot surveys, the Commonwealth allocated an unprecedented $A 1.4 billion for a National Action Plan for Salinity and Water Quality in 2001.

The program led off with a10 000km² airborne survey of the country around St George, in Queensland. The area had seen a big expansion of irrigated cotton using spate flow stored in huge ring tanks (which occupy 40 000ha on Cubbie Station alone); a risky operation because river flow is capricious, half the stored water is lost by evaporation, and it was feared that the whole operation was driving salinity across the flood plain. Contrary to received wisdom, AEM revealed salt in the thick clays that blanket the uplands (reaching seawater concentration at 40-60m below surface) but fresh groundwater in flood plain alluvium that is sporadically recharged by the rivers – so aquifer storage and recovery is a feasible alternative to surface storage. Modelling of flow from ring tanks suggested a groundwater mound would reach the surface within 15 years but the hydraulic conductivity of the soil is so low that, even after 100 years, half the head is dissipated within 2km; and land clearance will not mobilise salt to the rivers. The survey also revealed a hitherto unknown lobe of fresh water in 150m-thick alluvium, recharged by leakage from the Marannoo river. The immediate result was private investment in bores to exploit the newly found groundwater resource and to move surface water storages to impermeable soil (Dent 2007).

But it wasn’t a new dawn. To secure their support, the Howard government disbursed the National Action Plan funds to the States. Their land resources specialists weren’t going to spend the bonanza on someone else’s science and the monies were dissipated without tangible impact on salinity. At the same time, Australia entered the longest, most severe drought since colonization: water tables dropped and salt slicks shrunk or dried up, the county’s biggest river failed to reach the sea, city water supplies were in peril and water was completely withdrawn from the biggest irrigation areas. Salinity was no longer the big issue and public attention and funds were recycled into a National Plan for Water Security.
In the United Kingdom between 1945 and the early 1980s, there was strategic investment in agricultural science, and close integration of the activities of ministries and research councils of food and agriculture and overseas development. Subsequent retraction of government funding has shrunk the knowledge-exchange space; 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 agricultural science leaving blind spots in tropical agriculture, pest-and-disease management and field-based research including land resources surveys (Crute 2011).

Overseas presence has all but vanished and the cadre of experts is pensioned off; a few took up teaching positions but, without a career structure to attract a new generation, education and training in colleges and universities also withered; soil has even been dropped from the school curriculum. Much the same can be said of all the former colonial powers. The Soviet bloc created formidable institutions to deliver data for central planning but the inheriting states have struggled to maintain this capacity. In developing countries, where survey and research organisations were set up and funded by donor assistance, institutions collapsed when the external funding was withdrawn and there is no credible strategy for completing the work or, even, maintaining existing data (Box 6).

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**Box 6: A tale of two surveys**

Trapnell’s ground-breaking surveys of Northern Rhodesia were well-thumbed by a generation of Agricultural Officers but the only follow-up was the appointment, in 1954, of one soil surveyor based at Mount Makalu. Ten years on, the Government of newly independent Zambia requested international assistance. This was high noon for land resources surveys; FAO expert, Hugh Brammer, proposed a national soil survey unit and NORAD agreed to pay for expatriate surveyors who started to arrive in 1973. From 1977, NORAD funded the Zambia Soil Survey Unit (SSU) which became one of the most active survey organisations in Africa - securely funded, well equipped and able to undertake extensive fieldwork; several Zambian staff trained overseas. For five years, SSU was kept busy with *ad hoc* surveys for development projects but a further extension to 1987 prioritised systematic survey at scales 1: 100 000 and 1:250 000, and a national soil map at 1:1million. It was never clear who wanted the national map (finally completed in 1991); there was no attempt to assess national or local requirements. The professional staff ran the show themselves and much of the substantial output was highly technical - and remained unused; soil maps and land evaluation following the latest FAO guidelines were eschewed by the planners who continued to use the familiar Land Capability Classification (Wood 1981).

The agreement with NORAD specified a Zambian contribution increasing throughout the life of the project but this never materialised. When NORAD withdrew in 1991, SSU reverted to its line ministry with an impressive mandate but without the necessary resources. Any activity depended on sporadic commercial funding and collaboration with other agencies that were able to attract funding, such as the Wildlife Authority; demoralised staff left and the nominal complement fell to five in the 1990s and three by 2003. But upon transfer to the Zambia Agricultural Research Institute in 2004-5, SSU pulled itself up by its bootstraps. Work now includes services covering climate change (much in demand); soil conservation, soil testing and fertilizer recommendations; response to requests for information (200-300 per year for location-specific information and 5-10 requests for large areas); and, at the request of the Vice-President’s Office, survey and land evaluation of farm blocks between 15 000 and 100 000ha (one per province) to resettle people from droughty or flood-prone areas. SSU now has a staff of 30 (15 professionals) and has re-opened offices in Central, Lusaka and the Copper Belt provinces.

There is a parallel with the Dutch-funded Soil Survey of Kenya which completed the *Exploratory Soil Map of Kenya* at scale 1:1million (Sombroek and others 1982) and achieved fair coverage of systematic surveys. The dip in activity after cessation of overseas funding was mitigated by a 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 (when it comes to development, private investors call the shots) and KARI is hard put to keep its best staff in competition with the private sector and prestigious international and overseas institutions.
Research funds shifted to international agencies but the main beneficiaries, CGIAR institutions, abandoned research on production systems to un-funded National Agricultural Services; have never involved themselves in land resources survey, land use planning and extension; and have not created home-grown capacity in developing countries. International reviews suggest a continuing, worldwide loss of natural resources expertise; for instance the FAO *Global Forest Resource Assessment 2010* reports that the number of staff in post has declined by 1.2 per cent per year since 2000. Decline in national capacities to gather, maintain and interpret land resources information also impinges on the quality of global assessments (Box 7). Legal requirements for environmental impact assessment of large development projects constitute one of the few remaining national demands for land resources information (Box 8).

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**Box 7: Some global resource assessments**

**Fisheries**

Every two years, FAO’s Fisheries Department reports on *The State of World Fisheries and Aquaculture*, including 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 and 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 and most comprehensive (FAO 2010) 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**


**Environment**

Every five or six years, UNEP issues a *Global environmental outlook* compiled by specialists from national and international institutions and independent regional groups. Following criticism of the scientific quality of the earlier reports, GEO4 (UNEP 2007) assessed only peer-reviewed material and was moderated by a high-level consultative group. The Land chapter, which included the first measured global data on land degradation, involved 38 delegated specialists; every line of the text was negotiated - which reflected the uneven quality of the materials available as much as the various national and regional perspectives. Political pressure in the final adoption meeting led to a walk-out of some of the authors and a different team of specialists was assembled for GEO5.
Box 8. Farming systems and their social context: Veterinary Cordon Fence in northern Namibia

In 2006, the Government of Namibia proposed a $300 million, 5-year grant (MCA Compact) to the US Millennium Challenge Corporation for investments in the education, agriculture, and tourism. The agriculture component aimed to increase the value-added from livestock in the Northern Communal Areas (NCAs), where 57% of Namibia’s people live. A controversial aspect was a proposed new Veterinary Cordon Fence (VCF) along the Namibia/Angola border to help attain regional Disease Free Status from Foot and Mouth Disease. An existing fence, constructed decades ago, runs south of the NCAs (Figure 5); farmers to the south can export directly to the lucrative European Union market but Northern herders receive no such benefits - their cattle must stand in quarantine for 21 days before slaughter and, even then, can be exported only to regional markets.

Namibia’s Environmental Management Act, 2007, required that the proposed Compact be subjected to a strategic environmental assessment (SEA). Independent consultants conducted a preliminary assessment of the proposed VCF to inform the final design, involving assessment of existing data as well as community-based field surveys in the border areas in both Namibia and Angola. Baseline information for Phase 2 studies covering all components of the Compact was also gathered, including climate, geology, soils, water resources, vegetation and wildlife, land and resource use, livestock numbers, management and movement, human population and livelihood strategies (ARD 2008). Contrary to the official government position, the assessment showed that the new fence would disrupt the livelihoods of people living within 10 km of the border who regularly relied on pastures in Angola (the survey confirmed cross-border movements and provided photographic evidence of cattle swimming across the border rivers). Three development options were identified:

- **No VCF**: Keeping an open Namibia/Angola border would maintain flexibility of movement and reduce farmers’ vulnerability to an unpredictable climate but livestock markets would continue to be restricted and the current quarantine system would remain in place.

- **Construct the VCF in Year 3-4 of the MCA Compact** - allowing just 3 years to establish local governance, land tenure and other conditions to mitigate the negative impacts of the fence and to prepare the receiving areas for livestock that would be brought back from the Angolan pastures. Based on experience in Namibia and elsewhere in Africa, it would be unlikely that enough progress could be made in such a short period and several negative consequences were predicted:
  - High cost of mitigation
  - Social tensions in receiving areas if excess livestock were relocated within the NCAs
  - The fence and relocation would split herds, reduce availability of livestock that can be borrowed, and diminish employment - exacerbating poverty for HIV/AIDS-affected households and increasing school dropout rates
  - Disruption of migration for certain species of wildlife and consequently, localized habitat destruction, reduced viability of certain species (e.g. wild dog), and escalating wildlife/human/livestock conflicts near parks and in conservancies.

- **Construct the VCF after the Compact is complete** - using the Compact to ensure frame conditions are in place – keeping the southern Angolan rangelands accessible in the short term.

Taking account of the SEA, the Millennium Challenge Corporation deemed the proposed new VCF too risky and decided to eliminate the idea from the Compact.
Withdrawal of support for field activities came at the dawn of the digital electronic age so most field information remains on paper and it is not compatible with economic models or internet searches. In the world of soils, in Europe and globally, the most comprehensive sets of electronic data are provided by the European Soil Database (EC JRC 2003) and the Harmonised World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2012). Both deal with the various scales and different information contents of the source materials by transfer to a raster format according to the dominant soil type in each mapping unit but this procedure loses most of the information content of complex mapping units - and most soil mapping units encompass several kinds of soil other than the dominant one.

Another consequence of the loss of expertise has been increasing dependence on modelling and remotely sensed data - without calibration against field measurements. Long ago, even the International Training Centre for Aerial Survey warned: ‘it is evident that any attempt to map soils on photo-interpretation only is doomed to fail’ (Vink 1961). This can be demonstrated any day by fieldwork, not just in soils but in every other field of land resources, but a whole generation (perhaps two by now) has grown up in ignorance of the need for data verification that would be unacceptable in chemistry or physics.

2.2.2 Industrialised agriculture and sustainable intensification

The early successes of the green revolution encouraged unquestioned faith in industrialised agriculture that depends on technological innovation: irrigation, ever-more-powerful machinery, genetics, and agrochemicals. The consequences include the (now-disputed) notion that traditional, locally-adapted crop varieties cannot respond to inputs such as mineral fertilizer; it was believed that the complete package of modern crop varieties, intensive tillage and agrochemicals was essential to maintain ‘enhanced soil fertility’. Immediate results included in situ loss of locally adapted breeds of crops and livestock, and loss of most government funding for agricultural research and extension – the food problem was considered solved. More insidiously, simplification of production systems and acceleration of the trend towards bigger and bigger production units has undermined soil resilience, native fertility, biodiversity, ecosystem services, rural communities, and local knowledge of the subtleties of the landscape.
Fuel and fertilizer are no longer cheap; water resources are over-committed; globally, crop yields are levelling off - in the heartland of the green revolution, the Indo-Gangetic Plain, absolute yields and factor productivities stalled in the 1980s (Kassam 2011). And so we come full circle. Meeting the needs of the 21st century requires a paradigm shift: away from farming systems that depend on ever-increasing and increasingly expensive industrial inputs, to farming systems that put geography and biology back into land use and management (Dent 2013). Conservation agriculture and precision agriculture are more productive and less input-intensive than industrial farming but they are knowledge-intensive; their extension absolutely requires a new age of enhanced land resources information.

2.2.3 How and why did this happen?

Hugh Brammer has longer experience in soil surveys than most of us and is one of the few field scientists to have had personal input into the practical and policy decisions the surveys were supposed to support. His recollections (Box 9) underscore several common themes of the case studies presented later in this report:

Box 9: Recollections of an old hand

Hugh Brammer recalls:

‘When I was recruited in 1951 to survey the Accra Plains, in what was then the Gold Coast, it was explicitly to assess the suitability of the soils for irrigation using water from a proposed hydro-power dam on the Volta River. My boss, Cecil Charter, was setting up the Dept of Soil and Land Use Survey with specific objectives (that is the only occasion I recall that the objectives of the surveys in which I was involved were specified ) and the reports were prepared so that agricultural or forestry officers could make use of the information. Charter had been engaged to assess the suitability of forest soils for cocoa and he trained middle-school leavers in traverse-line cutting, measuring and levelling, sampling soils at regular intervals along the traverses, and recording vegetation and land use in a circle of 1-chain diameter around each soil sampling point. Each day’s samples and records were brought back to base camp where he or a trained senior assistant would describe and identify the soils, and eventually map the results.

‘In 1961, I was recruited as Deputy Project Commissioner on the FAO/UNDP Soil Survey Project of Pakistan. The Commissioner, RA Gardner, may have received instructions on the objectives of the proposed survey but I don’t recall seeing them. When the project eventually got under way, he organised training for newly-recruited national staff; he came from the US Soil Survey organisation and the methods taught were those of the US Soil Survey. We had good air photos and used them as base maps for field traverses to identify soil series and soil phases and to map soil associations. The interval between traverses varied between about 2 and 8 miles, depending on the complexity of patterns seen on the air photos and experience gained with time. I’m not sure of the rationale behind the sampling density but it may have been the need to survey Districts, averaging about 2000sq. miles, in the 5-month field season dictated by seasonal flooding. I visited the survey teams in the field to provide guidance, quality control and soil correlation. As the FAO staff completed their assignments, national team leaders took over under my continuing supervision and they completed the (by then national) survey early in the 1970s, after my departure.

‘Reports included land suitability assessments for various crops; with Robert Brinkman’s help, I adapted the USBR land classification for the seasonally-flooded, multi-cropped environment in East Pakistan. I don’t recall being instructed on reporting but, in our day, we were mainly thinking top-down: surveys for government planning of development. Because of the maps they contained, the reports were ‘restricted’ (not publicly available) but I tried to organise the findings so that they could also be used by research and extension staff. In practice, we found that these people couldn’t use them – or weren’t interested (not part of their work programs or what they had been trained to
The first reports were conventional narratives so, hoping to make the information easier to grasp, I changed them to present the soil and land suitability descriptions in tables. That didn’t seem to work, either. I later spent much effort seeking ways to present our information to potential users in other forms, including District/Subdivision summaries of development possibilities in less technical language and format but, at the end of my employment in East Pakistan, I wasn’t satisfied that our information was being used for any of its intended purposes. The only benefit that I am aware of was from technical articles that I wrote for the Pakistan Journal of Soil Science and lectures I gave in Dacca University which, I hope, benefited the students and their eventual careers. At that time, soil science was not taught as a field science: soil maps prepared by the Agriculture Dept before my arrival were ‘basket-of-eggs’ maps with boundaries drawn around the data points of chemical analyses of soil samples - including, in one case that I recall, a unit drawn around a misprinted pH value. None of my original recruits in 1962-63 had seen a soil profile and only one had seen a topographic map.

‘I was evacuated from East Pakistan in April 1971 and assigned to the Ministry of Rural Development in Zambia to introduce a team of Norwegian soil scientists to tropical soils. In the event, they didn’t arrive for over a year and I spent my time on soil surveys for various purposes. I don’t recall being instructed on how to carry out such surveys - I was an ‘expert’. The Ministry was interested in soil conservation so that was my focus but my travels were an opportunity for exploratory work. Before my departure, in 1974, I was able to draw a new soil map of Zambia and produce both technical and popular reports - I did eventually introduce the Norwegian team to soil surveying in a tropical environment.

‘At the request of the World Bank, FAO sent me straight back to Bangladesh, in January 1974. This was to help resolve a controversy between official opinion, that the new high-yielding rice varieties (HYVs) could be grown only under irrigation, and a lay view that they could be grown wherever traditional varieties were already grown. I reviewed the soils information we had gathered in the 1960s, interviewed rice-research specialists about the requirements of the HYVs, made field visits and then, with a Bangladeshi counterpart, went through all the District soil survey reports matching the HYV rice variety specifications with our findings. After four months, I reported to the Government, FAO and the World Bank, and took home-leave.

‘Inevitably, perhaps, I was invited back to help implement the recommendations. That opened up a wholly new career as an agricultural development adviser with the opportunity to put our soil survey findings to use in planning, research and extension: assisting with HYV programs, supporting the extension program, agricultural rehabilitation following natural disaster, providing land resources information for village-level planning and, eventually, a comprehensive agro-ecological zones study. I initiated a Thana-level land use planning program with a supporting training program and, in an attempt to embed land and soil information into land use planning, I wrote Thana and Upozilla manuals in the style of a motor-cycle maintenance manual - specifying all the relevant information and every activity - so that the most junior officer could accomplish each and every step (Brammer 1983). This only alienated the senior staff and, in the event, local planning was discontinued with a change of government. Unofficially, I also provided information to NGOs, including regular contributions to the NGO newsletter ADAB News.

‘I produced a great deal of grey literature that was invaluable when, after retirement, I came to write up my experience in Bangladesh (inter alia Brammer 2002) but it is hard to know how much this influenced decisions and land use at the time. Major flood control and irrigation projects were implemented without use of our information and, also without using our information, the farmers have increased food-grain production more than threefold since 1970.’

In short:

- Demand for information on renewable natural resources was driven by governments and international organisations that believed in progress through planning and the application of science and technology.

- Recovery from Second World War saw unprecedented investment in science, not least in agricultural science. Land resources information was poured into burgeoning government departments and, also,
agricultural extension services that translated it for land users; and high-level policy makers were served by a priesthood of special advisers. But the separation of responsibilities allowed land resources people write their own terms of reference; they were scientists dealing with fundamental information, not the problems of the day – and research became divorced from the world of the decision makers.

- Then that world changed. Governments lost faith in their ability to drive development, even in planning itself; the influence of governments waned as fleeting coalitions of public interest groups and NGOs found a voice; and the links snapped between the need for information and what was actually delivered and used. Land resources surveys were stranded – particularly when there was no institutional ownership of the information (whether generated by overseas consultants, a different department of government, or a previous administration of different political persuasion).

- In the UK, soils information that had been gathered at public expense was stranded by privatization - it disappeared and is now almost forgotten. Elsewhere, even if the central government were willing to release national data, the country’s states might object; e.g. in Germany where the Lander don’t agree to release the data, or in the EU where Germany and the UK blocked the release of a continental soil map unless the database was paid for and not distributed. In several countries, this information is a military secret and access is restricted, which has long been the case in the Indian subcontinent and even the broadest soil maps cannot be brought into the public domain in Saudi Arabia and Oman.  

- Without returning to command-and-control, strong arguments have been advanced for formal land resources policies and framework legislation. In Europe, the Soil Thematic Strategy (EC 2006a), which received common assent, called for a comprehensive approach to preserve soil functions on four fronts: awareness raising, research, integration of soil protection with other policies, and legislation. The first two have been shouldered to some extent by EU agencies but not noticeably by member states; under the EU Common Agricultural Policy, payments are withheld if minimum standards of husbandry are not met but, even if they were enforced, the standards set fall well short of sustainability. The proposed Soils Directive (EC2006b) was blocked in the Council of Ministers - the UK one of four governments opposed.

- It might be argued that land resources professionals failed to communicate the implications of their findings; in the case of the proposed EU Soils Directive, it was not for the want of trying - the European Commission was presented with more information than could well be digested but it might as well have been written in Old English. Be that as it may, today’s decision makers are unaware of the practical utility of land resources information. The practice of career administrators and project managers moving on every two or three years provides no consistent direction, and the old priesthood has been superseded by a new breed of consultants - few with rigorous grounding in fundamental science, none with links to institutions that can generate new and reliable information.

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

‘The nation which destroys its soils destroys itself.’
Franklin D Roosevelt 1937

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6A defensible position; amongst the earliest exponents of land systems surveys was MEXE, an experimental unit of the British Army which wanted to know whether its tanks would stick in the mud and other military questions (Brink and others 1966); and the first queries that FAO/AGL and ISRIC received from the USA after 9/11 was whether they had soil maps of Afghanistan.
Chapter 3

WHO NEEDS LAND RESOURCES INFORMATION and WHAT INFORMATION DO THEY NEED?

We manage what we measure. Closing the gap between actual crop yields and the best attainable under local conditions needs intelligence about every facet of the landscape. Where yields are already high, the focus is to minimise production costs and environmental impact, as well as incorporating novel demands like bio-fuels, which requires land information at a level of detail that is achievable but has rarely been assembled. Land resources information is also needed for urban, industrial and infrastructure development – where the costs of bad decisions are orders of magnitude greater than the total costs of the land resources surveys needed to avoid problems in the first place.

3.1 The need to know

Natural resources issues like food and water security, ecosystem services and climate change are, by and large, policy choices by sovereign governments. Their decision-makers struggle to appreciate what action is needed and what information they require to come to decisions - otherwise we wouldn’t have to be doing this exercise. First, they have to be convinced that political stability and economic development are underpinned by natural resources; this argument needs generalised information but with specific examples. Then they must go beyond mere recognition of natural resources and commit the physical and financial requirements of every change of policy. This requires detailed information and a head for detail. Equally, mechanisms and information are needed to call governments to account; if there is a fuss in the media, action usually follows.

To take just one problem area: sub-Saharan Africa still experiences the world’s highest rates of hunger and malnutrition (Sasson 2012, UNDP 2012). Food imports have increased from 5 per cent of total consumption in the 1960s, when most countries became independent, to 25 per cent now (de Graff and others 2011). At the same time, there have been big land acquisitions for bio-fuel and food crops destined for the international market (Borras and others 2011, Rulli and others 2013). The burgeoning cities and middle class are also eager markets but it is hard to mobilise local potential to respond to this demand; most farmers are smallholders producing essentially for household consumption. Cereal yields remain stubbornly low; the average is 1.2t/ha compared with 3t/ha in the developing world as a whole and, in many places, yields are less than 20 per cent of the potential (Lobell and others 2009, FAOSTAT 2013). Biophysical constraints are greater than in, say, south-east Asia (hard-to-access water resources, soil fertility decline) and there has been little progress in managing these constraints (Ehui and Pender 2005, Lal 2006, Sanchez 2005, 2010). There are many and various political and social reasons for this, including much-reduced public investment in agriculture over the last thirty years (IIAST 2009, Beddington and others 2011, Batiano and others 2012).

There is no prospect of wholesale use of western levels of fertilizer, power and irrigation: reserves of phosphate and water are not enough to meet such a demand. To close the yield gap, inputs will have to match the local soil, terrain and weather – so farmers will need and have and make use of detailed land resources information. But for half of Africa, the only accessible soil information is the 36-year-old 1: 5 million Soil map of the world; and for most of the other half, SOTER compilations at scale 1:1 million to 1.5 million. Using this legacy data, the Gates-funded African Soil Information System has generated
estimates of soil attributes at a nominal resolution of 1km. It has also promised new soil maps to be made by digital soil mapping - making use of the SRTM digital elevation model, satellite data, and sampling within sixty 60x10km so-called sentinel sites. This is still not what the farmers need but, if it can be delivered, it might provide a framework for management recommendations, identification of responsive and problem soils, and a new generation of field investigations and extension services.

Applications of land resources information are by no means limited to food security. For instance, the seasonal heave and subsidence of shrink-swell soils breaks up roads and buildings; it also snaps fibre-optic cables. This has been know for a long time but surveys to delineate problem areas invariably take place after the event - for example the current effort to mitigate the effects on the fibre-optic network in Australia. Again in Australia, the history of the salinity issue underscores the folly of relying on unproven models. Received wisdom (jumping to conclusions from rather few field observations) proclaimed a need for unaffordable, landscape-wide mitigation. New information from airborne geophysical surveys reveals precisely where the salt lies in the landscape and the groundwater flows that carry it to where it is not wanted - such as major irrigation schemes, municipal water supplies, and costly infrastructure. With this information, surgical mitigation becomes entirely feasible (Box 5).

What is needed, always, is good information at the point of decision - which is most likely to materialise when the supply of information is driven by the decision-making process. Otherwise, decisions are taken in ignorance. Uninformed, bad decisions have been responsible for many so-called natural disasters: for instance the 2010 floods in Pakistan were catastrophic - not because of unprecedented rains but because deforestation and soil erosion in the Indus catchment had curtailed its capacity to retain rainfall, and because of reckless urban development on the flood plain without provision of holding basins.


Different groups of decision makers have different needs:

- **Policy makers** in government and international agencies need intelligence to deal with food, water and energy security, climate change, land scarcity, and contamination of land, water and air that impinges on public health. Information is needed at an appropriate level of generalisation to establish if there is a problem, the location of the problem, and whether the means exist to deal with it. And politicians want results now: they are elected by the present, not the future, generation so environmental issues are judged by their immediate economic importance.7

The first requirement may be for national information but even global information is needed to assess food security and climate change. Land evaluation (as opposed to primary soils, vegetation, hydrology and climatic information) is needed to identify development opportunities and constraints, and for planning appropriate interventions which, like roads, may not necessarily be agricultural. 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. Land resources information is also needed to enter dialogue with land users who already have

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7 Briefing the German Minister of Economic Affairs, scientists of the European Soils Network reeled off various aspects of soil degradation: the only one the Minister was interested in was landslides. He laughed when told about soil compaction.
local knowledge and experience.

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

- **Local communities and land managers** need better intelligence so that they can read the signs of health or degradation in their landscape, improve the quality of land and water management, and target community action. Information is needed at the field scale - where the action is. In particular, detailed information is needed for precision agriculture to increase production and, at the same time, safeguard the environment. This applies equally to countries with big commercial farming operations struggling to maintain profitability, and to developing countries with many smallholders who need to adopt new practices to make the transition from subsistence to commercial farming or from field crops to horticulture.

There has always been a military need for topographic surveys and meteorology, strongly supported by the demands of shipping, aviation, overland transport and public utilities. Oil, gas and minerals industries have consolidated into big, 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 natural resources remains fragmented and relatively, sometimes absolutely, small-scale; individual enterprises and local communities have neither the interest nor the resources to undertake extensive surveys. Solutions to issues of land use and management, and competing claims on land and water resources require security of expectations and political leadership, so systematic gathering and management of fundamental information has been driven by governments. But the task of providing comprehensive information at the field scale has defeated most centrally-funded organisations.

### 3.1.2 How much?

Key questions of land resources, globally and nationally, include:

- 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 the water resources and how may they be conserved?
- How much carbon can be feasibly stored in forests and soils? At what rate can this carbon be fixed, and how permanent is the 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. Often, the critical issue is to calculate stores and fluxes of water, carbon, nutrients and salts, which requires measurements and estimates of the rates of change. Good answers may require a combination of survey, monitoring and modelling; and some questions can only be attempted 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 still depends on measured data for running and validating the models.

Market-related initiatives like carbon, water and salt trading need 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. However, even reporting the status of resources is hamstrung by the lack of well-accepted measures of fundamental parameters like vegetation cover, soil fertility, water storage and carbon storage. Assessment of the viability of a trading mechanism requires translation of biophysical measures in terms of natural capital, ecosystem services, and the benefits and costs of different management options. Tracking change also requires simple kits to measure indicators in the field; the only important attributes that can be easily monitored at the moment are salinity (through electrical conductivity) and reaction (pH).

At the grass roots, managers need information at the field scale to take account of and take advantage of local variability. They need detailed 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 that is lacking almost everywhere. Equally, decision-makers need ground rules to assess their own performance. Some kinds of projects are harder than others (least likely to be successful are livestock projects, development of poor rural areas, and projects that depend on cooperation between more than one government agency). Factors for success include political stability, support by government for local issues and local participation, a single powerful agency in control, good scientific information and skilled technical staff, and good public relations (Kwakernaak 1995).

A 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 policy, planning and management. One of the hardest tasks for policy-makers and managers is to test and integrate the various strands of information that may now be supplied 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.

3.2 Soil information as an exemplar

The state of soils information epitomises information about renewable natural resources in general. Consistent data are lacking at local, national and global levels. And though many of the most important attributes change significantly within our lifetimes, most of our information is more than thirty years old.

Decision makers wanting to develop and conserve soil and water resources need answers to the following questions: What is the soil like and how does it vary – or what kinds of soil are present and what is their distribution across the landscape? What is the condition of the soil? What is its capability and how does it restrict land use, the choice of crops and crop yields? How should productive land (and barrens) be managed and how can degradation be arrested? Soil surveys provide the answers to the first two questions; the next two questions are a matter of assessment, which must also draw on field experiments, but all the information depends on three primary data sets: soil profiles, maps, and grids:

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8Conscious of the need for field-scale information, the Soil Survey of England and Wales began mapping at six inches to the mile (1:10 560) but could never finish the job. Resurgent demand from precision agriculture now has few people to turn to and 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; little or no direct use is made of the national soil survey data.
Soil profiles: descriptive and measured data for individual observation sites. Profile descriptions include the site, soil morphology, and biophysical attributes (some measured in the laboratory). ISRIC–World Soil Information maintains two scrutinised global datasets: 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 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 individually delineated parcels of land. Each delineation is named according to the kind of soil or combination of soil and terrain (land system) categorised by a hierarchical classification 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 this is a personal interpretation and another surveyor will produce a different one. Mapping criteria are not explicit and the surveyor’s mental model never recorded - so the map cannot be recreated or updated. Moreover, sampling intensities are rarely enough to test the presumed relationships between the observed landforms and vegetation and soil mapped; reliability is rarely recorded. Coverage is uneven; few countries have matched the USA and China in achieving consistent, national coverage at a semi-detailed scale; most surveys stuttered to a halt without achieving even minimal coverage at the required level of detail and, once a survey organisation closes down, its legacy data are at risk.

Soil grids: The format of conventional soil maps is incompatible with other datasets that are held electronically as grids of attributes creating continuous surfaces, as opposed to discrete parcels of land. Digitising the original soil maps doesn’t 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 succeeded 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.’

Recent advances have made national or global grids feasible: open access to the SRTM 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 of comprehensive chemical analysis from hundreds of dollars per-sample to ten. Some five years ago, the Gates-funded Africa Soil Information System undertook to create a grid for Africa with detail better than 1km and a calculated index of confidence for each pixel; and GlobalSoilMap.net promised a comparable world soil map. Disagreement soon arose between national parties that believe a grid at the maximum resolution of the DEM (100m) will attract substantial funding for their institutions, and old hands who know very well that the present knowledge base is not good enough to produce even a 1km grid - all that has been delivered to date has been derived directly from legacy data.

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9 See case study and http://www.isric.org/projects/world-inventory-soil-emission-potentials-wise
10 Belgium and Czechoslovakia achieved national coverage at 1:10 000 or better but see, also, case studies for Australia and Zambia.
11SRTM: Shuttle Radar Topography Mission: http://www2.jpl.nasa.gov/srtm/. See Section 3.4.1
The digital era dawned just as support for field surveys was withdrawn, which may or may not have been coincidence, and recent activity has been confined to re-processing old data into electronic format. The most comprehensive global dataset is the Harmonised World Soil Database (HWSD) is a 30arc-second raster compiling national data derived from some kind of systematic survey (FAO/IIASA/ISRIC/ISSCAS/JRC 2012) but there are still big gaps filled by the 1:5 million-scale Soil map of the World (FAO-Unesco 1971-1980) which calls for a word of warning: 1km-resolution is not justified by the resolution of the Soil map of the world. The 1km-grids of individual soil properties have been derived by transfer functions from the dominant soil taxonomic units. This procedure loses much of the original information and is in no way comparable to digital mapping of individual soil attributes; the same applies to the ‘improved’ global soil property database at 1km-resolution released by ISRIC which is based on HWSD and the WISE database (http://www.isric.org/content/soilgrids). The European Soil Database (ESDB, http://eusoils.jrc.ec.europa.eu/ESDBArchive/ESDB_Data_Distribution/ESDB_data.html) also deals with the various scales and information content of source materials by transfer to raster format according to the dominant soil in each mapping unit. Extended information on characteristics of the mapping units such as elevation, slope and land use (originally recorded as qualitative data) has also been generated using pedo-transfer rules but there are almost no soil data for built-up areas. Both compilations contain errors and inconsistencies in the transfer of data into a standard format - and the errors are compounded when the datasets are used within a GIS to derive maps individual and combined soil and land attributes that find their way into policy documents, e.g. Europe-wide maps of soil carbon storage (Jones and others 2003); such errors may be mitigated by sophisticated comparative analysis (Heiderer 2013) but this is rarely undertaken.

Global generalisations are mainly of academic interest. For practical purposes, soil information is needed at the scale of management (1:25 000 for extensive farming enterprises up to 1:5000 or better for intensive agriculture, urban and infrastructure development). In countries where there is still an active soil survey organisation, this should be the first port of call: for instance in the USA, the Natural Resources Conservation Service (http://www.nrcs.gov/wps/portal/nrcs/main/national/about); Canada and Australia (respectively http://sis.agr.gc.ca/cansis/nsdb/intro.html and http://www.asris.csiro.au) also have functioning land information systems incorporating the data formerly gathered by State organisations. The wealth of soil information collected in Europe is listed by Bullock and others (1999) but is now hard to find; for many of the larger countries in Western Europe, the ESDB at 1:1million is the best available. Soil maps of Germany, Italy and the UK are not in the public domain.

In contrast with developing countries and most of the western world, soil surveys in the United States achieved detailed national coverage and wide application because the information was demanded by a powerful national institution that knew what it wanted – the Soil Conservation Service (now the Natural Resources Conservation Service, NRCS). In recent years, NRCS has had to weather a succession of deep cuts in funding but ongoing demand for its information enables it to maintain an active survey program and take on board new developments; and the USA still has a large knowledge exchange space - strength in numbers means room for excellence and new ideas that are handed on to the next generation.

Surveys were carried out at a detail and level of information tailored for use by professional extension agents to help individual land users. They are still so used thanks to continuing efforts make the information useful and accessible, not just for agriculture but for business, domestic and pleasure. Both the fundamental data and more than one hundred interpretations are freely available and, since 2005, have been delivered through Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm). The

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12Relative strength in land resources is reflected in membership of learned societies. Membership of national societies of soil science ranges from 10 000 in China and 6 500 in the USA; to Germany 1 980, Brazil 900, Australia 725, United Kingdom 700, South Korea 530 and 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).
standardised digital data at scales 1:63 360-1:12 000 and 1:250 000 are overlaid on imagery from Bing. More than 6500 users access the Web Soil Survey every day and more than 15 000 customised soil survey reports are created every month, serving soil and water conservation as well as project planning (Greene 2013) and on March 1st 2013, NRCS released a 10m-resolution Gridded Soil Survey Geographic Database (gSSURGO) to meet the demand for soil geographic data for desktop geographic information systems.

In the United States, soil survey information is also used to create and maintain national data for Important Farmlands (categorised as Prime, State-wide and Local Importance, and Unique). The last complete National Resources Inventory, published for data collated in 2007, documents a loss of 14 million acres of prime farmland since 1982 – mostly through urban and industrial development. In compensation, thanks to the availability of good soils information, investment of $40/ha/year on conservation of arable land has reduced erosion rates from 177 t/ha to a sustainable 1 t/ha for most cropland; expenditure on pastures is about $5/ha/year; a total investment of $6.4 billion/year brings a return of $44 billion/year in increased value of crops, livestock, water supply and recreation (Pimental and others 1995).

Things are different, too, in China (Box 10), Korea, Brazil and, maybe, India (Box 11): survey and planning organisations are alive and well in countries with strong bureaucracies and strong economies, especially where they have long been influential departments of government. China and Brazil are investing strongly in their natural resources capacity, including research and extension, 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.

**Box 10: Land resources information in China**

China supports 22 per cent of global population with only 7.2 per cent of the arable and a gap is opening between real and required production. Buying up land offshore can have only a marginal impact so sustainable management at home is essential to meet people’s needs and aspirations. As the world’s fastest-growing economy, China makes huge demands on natural resources and needs to shift from high consumption for low benefits (and devastating effect on the environment) to a green economy and this new direction was foreshadowed in the 2013 Communist Party of China Central Committee: ‘The building of an ecological civilization will be accelerated; a system of compensation for the use of natural resources and the subsequent impact on the ecosystem will be established soon.’ For the first time, this draws a ‘red line’ for ecological protection and considers payments for the use of resources and ecosystem services.

What is envisaged is more-subtle use of resources informed by resource appraisal and monitoring, and coordination of plans, executive orders and management on the ground. Historically, different departments have undertaken large-scale studies and investments according to their own objectives; the result has been lots of contradictions. For instance, on-going land degradation afflicts 24 per cent of the country; dry lands have attracted most attention and China is one of very few places where the effects of individual land reclamation schemes can be seen from space - but most of the degrading areas are actually in the wetter, more densely populated south-east (Bai & others 2013); and there are countless examples of land reclamation without cultivation and forest protection without consideration of local livelihoods. President Shi has convened an over-arching committee on the Green economy to overcome the dislocation between top-down planning and horizontal links between parallel departments and give precedence to collective interests. For a behemoth like of China, this is a big ask.

Land resources are administered by a powerful bureaucracy that needs to be well informed. Various institutions promulgate professional standards and have established key laboratories led by a new generation of internationally-trained scientists and making full use of the latest technology, including remote sensing with the Sino-Brazilian earth resources satellites. Policy guarantees key projects and those related to wellbeing, such as housing and
maintenance of farmland for food security, going so far as transferring industrial development to deserts and enforcement of land zoning by closure of wells. The Ministry of Land Resources (MLR) reckons that at least 120 million ha of arable is needed for food security; 2007 figures were (in millions of ha) arable and horticulture 134, forest and pasture 498, other agricultural uses and water conservancy 62, urban, industrial and infrastructure 30. A brake on the loss of farmland has been applied through the tax system and enhanced protection; at the same time, farmers are subsidised according to the quality of their land. But there is a flight from the land; as much as one third of land in agricultural regions is abandoned and the rural population is projected to fall from its present 300 million to 280 million by 2020 (Liu and others 2009). Geo-hazards, especially flooding, cost billions of yuan and hundreds, even thousands of deaths every year. Responses include geo-engineering, training in rural geo-hazard control reaching three million people; monitoring and early warning; and emergency relocation of tens of thousands of people.

When demands are made for land resources information, the responsible institutions deliver:

- Nationwide topographic survey is complete at scale 1:50 000 and the Bureau of Survey and Mapping is now focussing on the national geographic information database, a digital urban geospatial framework, and a high-resolution stereo-mapping satellite. Land resources surveys under the Academy of Land Survey and Planning have been completed at scale 1:10 000 for 2 million km², 1:50 000 for 620 000 km², and 1:500 000 for 1.2 million km² (2731 land resources survey reports are extant) and monitoring programs serve land administration, law enforcement, and an annual review of land-use change.

- As a separate activity, soil surveys are undertaken by the Institute of Soil Science, Academy of Sciences. The Second National Soil Survey, completed over 16 years beginning in 1979, involved more than 84 000 scientists as well as supporting staff. Agricultural areas were mapped at 1:10 000-25 000, forest and pastoral areas at 1:50 000, rangeland at 1:200 000. The six-volume Soil Series of China describes nearly 3000 soil series with field descriptions and analytical data. Beginning in 1992, the semi-detailed maps have been condensed to a 1:1 million-scale soil map comprising 64 sheets with 909 mapping units, mostly soil families; the minimum delineation is 25 mm² (25 km² on the ground) for forest and pasture land, 16 and 4 mm² (16 and 4 km² on the ground) in agricultural areas and places of scientific interest; and a digital version now supports research, education and planning of agriculture, water and forest resources. For international comparisons, the Institute of Soil Science is working up a Chinese Soil Reference System based on information from Soil Series of China, correlating respective attributions with Soil Taxonomy and the World Reference Base.

- A nationwide soil pollution survey led by the Ministry of Environmental Protection in 2006-10 involved one thousand organisations and 20 000 professional and technical personnel. Some 214 000 soil samples were taken for analysis of heavy metals, arsenic, and organic pollutants. Outputs include evaluation of soil quality and contamination, risk assessment, planning of remediation, and establishment of a system of soil-environmental quality monitoring and management.

- An exploratory multi-objective geochemical survey was launched by the China Geological Survey in 2002, funded by MLR and Provincial Governments and extended nationwide during 2005-2008 (on instructions of Premier Wen Jiabao). More than 500 scientific and technical staff have been involved and, up to 2009, more than 100 000 people collected 600 000 samples; 23 laboratories were set up for analysis of 54 elements (32.4 million determinations). Follow-up investigations in the Yangtze and Yellow River basins, NE plains, and coastal economic zone appraised soil fertility and heavy-metal pollution and prospects for eco-friendly production. Investigations of Quaternary sediments and soil parent materials have added new parameters for geological mapping, energy and minerals development; and systematic soil organic carbon data indicate potential for carbon sequestration.
Box 11: Resource survey organisations in India

National Bureau of Soil Survey and Land Use Planning

The All India Soil Survey Organisation was established in 1956 under the Ministry of Agriculture to undertake soil surveys for development programs, operating from New Delhi and seven regional centres. In 1958 it became the All India Soil and Land Use Survey, merging with the Land Use Planning Scheme of the Central Soil Conservation Board to carry out surveys for Major River Valley projects. Research was later transferred to the Indian Council of Agricultural Research (ICAR) while development activities remained with the Ministry. In 1976, ICAR set up an independent National Bureau of Soil Survey and Land Use Planning which relocated in 1978 to spacious new premises in Nagpur; 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 USDA with 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 made little impression on the subcontinent. Dynamic leadership by JL Sehgal created a truly national mapping program (Sehgal & others 1987) and all India was mapped at 1:250 000 – 1:500 000, beginning with West Bengal (Haldar & others 1991) and completed by 1999. This was made possible by Landsat imagery and assisted by training provided through the UK Natural Resources Institute. Surveys began with land systems interpretation of satellite imagery supplemented by geological and topographic maps; then field survey to correlate soils with landscape elements along sample strips cutting across the elements identified by remote sensing and, also, regular observations on a 10km grid; finally, transfer of the field maps to 1:250 000 base maps and laboratory analysis of grid samples and benchmark soils. The legends include plain English descriptions of each mapping unit e.g. ‘deep, poorly drained, clayey soils, very severe salinity’ and the Soil Taxonomy equivalent, in this example Typic halaquept.

But under subsequent Directors, the Bureau has slept. Attention reverted to ad hoc surveys at larger scales and the use of land resources data in a District Planning series but the data are not in the public domain and, even when people are prepared to pay, the Bureau is unwilling to release them. Degradation of farmland and over-exploitation of water resources are obvious; factor productivities for most crops are declining; but there is a lack of site-specific data and situation-specific recommendations.

Forest Survey of India (FSI)

FSI was established in 1981 under the Ministry of Environment and Forests, succeeding the Pre-investment Survey of Forest Resources initiated in 1965 sponsored by FAO and UNDP. 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
- 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.

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 and sustainably
develop forest resources. 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. KFS is coordinating and supporting other agencies and NGOs in Kenya to design and implement specific forest monitoring and inventory projects - but we are unaware of any collaboration with the Kenya Soil Survey or National Agricultural Research Laboratories.

3.3 What do decision makers actually use and where do they get it?

3.3.1 What do they want?

What are their agendas, commitments, doubts, constraints, problems, and the blockages to use of land resources information?

We need to do the research to answer these questions: to compare information needs with information used; the timeliness, degree of detail or generalisation, reliability, comprehensibility, credibility and value for money of land resources surveys; to assess access to information and expertise, maintenance of public datasets, and stability of institutions. The scanty literature includes a survey of soil map users in British Colombia (Valentine and others 1981), a European Soil Bureau Network questionnaire to potential users of the Soil Atlas of Africa, a needs assessment for the Australian Soil Information System (Wood and Auricht 2011), and an on-line survey by the FAO Global Soil Partnership (FAO 2013b). Notwithstanding the caveat that there is more to land resources than soils, two things are remarkable about the outcomes of these surveys. The first is their similarity: all demand site-specific information for areas of concern; easy access (nowadays this means delivery through the worldwide web); consistent, authoritative data on soil thickness, texture, slope, soil water, soil organic carbon, nutrients, toxicity and biology; and meta-data about mapping and analytical procedures. The second is their unworldliness. The give-away is the cry for meta-data that might enable users to test and refine the data for their own particular applications: nearly all the respondents were researchers - not policy makers or planners and certainly not farmers or engineers who will have no truck with information that they cannot use as it stands. A different approach is required to ascertain the needs of decision makers, focusing on areas where information is in greatest demand, which is in places experiencing the greatest change (Appendix 1 is a diagnostic embracing the political context and the participants, as well as specific questions on land resources information).

Our own experience is that there is no felt need for our information from policy makers or farmers whom we might expect to be the prime users. Decision makers want to minimise their exposure to risk and politicians have an overweening interest in re-election; if they have any interest in the land, it is in known trouble spots like landslips, dust storms, water supply, floods, salinity and pollution; it is hard to maintain interest in longer-term issues like food security and climate change.

Policy development and feasibility studies require generalised information. Maps enable relevant information to be added layer by layer and, at this level, small scale is a virtue - detail is needed for implementation. But decision-makers can’t use soil maps or any other arcane land resources data: the data have to be interpreted for the decision in hand - clearly and simply, ideally as a one-shot answer:

Build? Yes or no.
What? a, b or c.
Here? Yes or no.
Risk? Yes or no.
This is the point at which land resources expertise might be called upon but private persons will not pay for expert interpretations of technical data and governments cannot wait, so off-the-peg interpretations have been developed. Still the most-widely-used are the US Bureau of Reclamation classification for planning irrigation projects (USBR 1953) and the USDA Land Capability Classification drawn up 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 and has been widely copied - sometimes for purposes for which it is ill-suited: the more sophisticated FAO Framework for Land Evaluation (FAO 1976) was harder to sell. America has also given a lead with standard interpretations of each mapping unit for a range of specific purposes from construction to sewage absorption fields - but no one else followed: no one else has maintained such a well-organised and well-funded extension service.

Commercial farmers want to maximise their returns on investment; they are eager for advice on soil fertility, soil water management at the field level, and land suitability for a range of commercial crops. Such advice may or may not be available; big farmers are turning to private surveys for the detail they need and to agronomists to provide field-specific recommendations. Subsistence farmers have other priorities that make land resources issues irrelevant; they have no choice about where or, lacking access to inputs, how to farm but they do look for the best return on their labour. Most land users have no links with technical information but the Comilla project, in Bangladesh, demonstrated that once various government departments were located in the place where mechanics and cooperative leaders came for weekly training and where community groups also met, local people took matters in hand for themselves (Khan 1983). Farmers’ field schools can help farming communities to explore their own resources, systematise their experience, identify their constraints and try out options that promise more stable, higher returns and lower costs. Once the farmers are well along this path, with a conscious and structured understanding of their own resources, they are in a position to demand, and make use of, properly interpreted technical information. Harking back to the perspective of policy makers and high-level administrators, field schools for them can transform their outlook too.

Urban land developers also want to maximise the return on their investment and, if they might be called to account, minimise risk. They are interested in hazard assessment and detailed soil engineering conditions like regolith\textsuperscript{13} thickness, drainage, soil texture and shrink-swell soils – information that is often lacking but which can often be provided at first pass by shrewd interpretation of semi-detailed soil maps. Development agencies may have a more nuanced perspective, including baseline conditions and the environmental impact of development proposals but, beyond national-level or regional land resources studies of variable quality, this information is hardly ever available.

3.3.2 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 an insight to the text: to the users, it was the map that mattered - it was pinned on the wall but 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 have almost replaced the paper map and report. Survey procedures have been transformed by advances in remote sensing: digital elevation models, an array of satellite-borne instruments that provide global coverage and increasing detail, and airborne geophysics that opens a new window on the world. Slow and costly laboratory analysis may soon be superseded by infra-red spectroscopy, although we are still short of useful field tests. Rigour and confidence have benefitted from the application of advanced statistical methods and measures of uncertainty. And more tangibly from

\textsuperscript{13} The uppermost, weathered part of the solid Earth, above fresh rock and including soils
the users’ point of view, geographical information systems enable competent professional staff to present and integrate a variety of data from different sources. Yet, just as all this is being won, it is being lost as satellites fall and information is forgotten. Digital data are ephemeral; there is no strategy to maintain them and no assumption of responsibility. The Worldwide Web has revolutionised access to information but doesn’t exert peer review or the judgement formerly provided by in-house professionals. It is asking a lot of busy decision-makers to seek and find and query technical data through a land resources data system - and they don’t. Loss of the professional cadre means that not only is less natural resources information is used now than formerly but its quality is unknown.

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 databases from the extant data for about half the land surface at scales of 1:1million or 1:5million. The recent FAO guide to the available global and regional soil information (2013) gives no leads to the detailed information required for action on the ground; ISRIC and WOSSAC hold international collections of this kind of information14 and there are a few national archives - but their continuation is precarious.

Climatic data are 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 and super-computers, but global climatic data are 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) which do not have access to all the available data. The historical datasets needed to assess climate change have been accrued by a few interested individuals and, sometimes, maintained in an amazingly amateur fashion. 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).

By definition, renewable natural resources change over time. Measurement and prediction of these changes are fundamental to our understanding of processes like land degradation and carbon storage, and are essential for market-related incentives like carbon, salt and green water credits. But monitoring of these changes has rarely been attempted by regular surveys; reliance is placed on proxies and simulation models that do not command the same confidence as real measurements. For slowly changing systems, the best information comes from long-term field experiments like those established at Rothamsted (since 1843); Grignon (1875) in France; the Morrow Plots in 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 periods at a few other sites.

3.4 New activities and advances in knowledge

3.4.1 Digital elevation models

Digital elevation models (DEMs) have supplanted conventional topographic maps in many applications including modelling the incidence of solar radiation, rainfall patterns and drainage. Ecosystems, soil patterns and the migration of animals are also intimately linked to elevation, landform and aspect.

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14The World Soil Survey Archive and Catalogue (WOSSAC, http://www.wossac.com/) incorporates the substantial archive of the former Hunting Technical services including maps and reports, air photos and film, as well as materials from the Land Resources Division and home soil survey organisations.
Early DEMs were laboriously constructed from topographic maps. Pioneering development of sideways-looking airborne radar for the RadamBrazil project, 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 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 (SRTM 2004 http://dds.cr.usgs.gov/srtm/, CGIAR-CSI 2004), now generally available at its full 30m resolution (http://asterweb.jpl.nasa.gov/gdem.asp).

Remotely sensed elevation data have shortcomings: voids in areas of strong relief, deduced stream lines are often wrong, and the surface measured is the top of the vegetation canopy - not the ground. 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 and ecological patterns. SRTM is already taken for granted and digital elevation data continue to improve along with measurement technology. New global DEMs are being acquired that will replace SRTM in the years ahead: airborne LIDAR\(^\text{15}\) already 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; the TANDEM-X satellite radar system will potentially produce global elevations at 2-3 times better resolution than SRTM. But 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.

### 3.4.2 Predictive ecosystem mapping (digital mapping)

Lack of useful information for large areas and the cost, slow progress and uncertain accuracy of conventional surveys have encouraged the application of predictive models to land resources survey. This is founded on two premises: first, a general understanding that ecological patterns are controlled by environmental gradients (moisture, energy, nutrients) that are, themselves, determined by topography; secondly, the assumption that spatial patterns of ecosystems, soils and their various attributes can be predicted by formalising field experience into rules that can be applied to existing digital datasets (Zhu & Band 1994). So topo-climatic attributes computed from a DEM may be used to derive 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, Boettinger 2010). Predictive (or digital) mapping brings a quantitative approach that was hard to achieve in the past but it is impossible to overstate the importance of the second premise - whatever the technical wizardry applied to the original data, predictive mapping depends on the quality of the field experience used to draw up the rules.

For mapping 8million ha of the forested Cariboo region of British Colombia, MacMillan and others (2007) defined mapping units using local knowledge of the site attributes 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 1:25000 and 1:50000). These data included maps of bioclimatic regions, regolith thickness and texture and, also, topographic elements derived from the DEM (slope gradient and curvature, relative landscape position). Rules for automatic recognition of patterns were drawn up 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

\(^{15}\) LIDAR: Light Detection and Ranging is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminating it with laser light and analyzing the backscattered light.
value matching the concept of the class (e.g. steep slopes). Weightings were based on expert knowledge; preliminary results were tested against expert knowledge and field examination, and refined or re-defined until an acceptable outcome was achieved. Then the rules were applied to the assembled input data to produce a seamless mosaic of predicted values. Independent assessment found the predictive maps achieved better than the minimum acceptable accuracy of 65 per cent - and outperformed conventional mapping procedures at a fraction of the cost.

This is classical free survey procedure except that the surveyor’s mental model of the landscape is written down as formal, numerical rules that can be tested and improved with further knowledge - for instance, ancillary information from different sources such as geophysical surveys (see 3.3.4 below) can be incorporated. And the map is drawn by a computer that follows these rules exactly and consistently. A great attraction of this approach compared with conventional field survey is that it can generate unique soil information for any single point on the map and compute an estimate of errors. Many digital soil mapping (DSM) case studies have found that the classical soil maps were imperfect but these studies have rarely covered more than 10km². Up-scaling has proved problematic for many important soil properties such as salinity and sodicity (unless independently mapped by geophysical survey), soil thickness and profile morphology. It is easy to promise too much - as was demonstrated by the expensive failure of a pioneering nationwide digital mapping program undertaken by CSIRO Australia in the 1990s; there are many pitfalls - lack of data to properly model the classes of interest, lack of expertise, lack of time to thoroughly explore, understand and apply the most appropriate processing and classification methods, and underestimation of the time and effort needed to establish ground truth.

Digital mapping procedures are summarised by van Engelen (2012) and FAO (2013b). Substantial trials in the USA include a primary survey of the North Cascades National Park, Washington (Frazier and others 2009), an ongoing project to integrate initial soil survey with land-type and ecological site inventory on the White Mountain National Forest using a LIDAR soil landscape model, and several projects to update and refine mapping already accomplished by conventional procedures. Internationally, digital, mapping is now being applied to the African Soil Resources Information System (http://www.africasoils.net) and GlobalSoilMap net (www.globalsoilmap.net).

3.4.3 Normalised Difference Vegetation Index (NDVI) applications

Natural resources surveys 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 says it all: ‘The exciting and totally unexpected success of AVHRR in applications for which it was never intended’ (Cracknell 2001). AVHRR is the Advanced Very High Resolution Radiometer mounted on NAASA meteorological satellites – actually very low resolution (1km), even compared with the Landsat satellite data already being collected at the time (30-60m), but its large field of vision and daily global coverage made it ideal for global monitoring. And by chance, the ratio of red to near-infrared radiation (NDVI) measured by the radiometer is a good indicator of vegetation dynamics; Bai and others (2008) used corrected monthly NDVI values extending back to 1961 (Pinzon and others 2007) as a proxy assessment of land degradation and improvement. The 25-year NDVI trends (Figure 4) revealed a global picture quite different from received wisdom and, predictably, the ‘experts’ met the results with the usual public reaction to a new truth: ‘It’s not true’; and then, ‘It’s against scripture’. We are still waiting for the final accolade: ‘We knew it all along.’

Satellite data become more and more valuable as the period of consistent data lengths and further layers of information are uncovered (de Jong and others 2011, Bai and others 2013). More-recent satellite-borne sensors yield more-detailed, more-direct measures of NPP, e.g. MODIS data, acquired every three days with a spatial resolution of 250-1000m, provide a continuous NPP dataset derived from the fraction of absorbed photosynthetically-active radiation (Running and others 2004). However, these newer sensors
cannot match the thirty years of consistent NDVI data that now reveal the changing trends in land degradation (Bai and others 2014).

### 3.4.4 Geophysical surveys

Satellite remote sensing can only be a proxy for the condition of the land - there is no passive system that can see below ground. But airborne geophysics, which was developed for minerals exploration (Darnley & Grasty 1971, Grasty 1979) can see below the surface. Radiometrics measures natural γ-radiation from 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 it is wet. Results are reported as individual-element counts or as ternary maps computed by assigning colours to each element and 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 is incorporated in illite clay and may be adsorbed by other clay minerals; in contrast U and Th are associated with resistant minerals like zircon that accumulate in strongly weathered soils). From Australian experience, combination of radiometrics with landforms analysis lends rare insight into soil patterns (Cook and others 1996, Wilford and others 1997, 2001) that 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, most conveniently measured by electrical conductivity. This can be mapped in three dimensions to more than 100m below ground by airborne electromagnetics. In dry lands, salt is held as briny pore fluid in the regolith; 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 detected by a receiver towed behind the aircraft; and the signals are translated into a three-dimensional map of conductivity that can be calibrated against borehole measurements of salinity. Airborne magnetics reveals geological structure including magnetic gravels that may serve as conduits for groundwater, 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 at a cost of about one $US/ha and, from these data, the outcomes of management interventions may be assessed (Dent and others 1999, Dent 2007). Low-budget work may be undertaken with ground-based electromagnetic survey (e.g. Buchanan and others 2012, Woodforth and others 2012 in Australia) and with ground-penetrating radar.

### 3.4.5 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. However, soil- and plant-testing services played an important role in the rise of ‘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 agricultural advisory services, but their effectiveness depends on calibration against actual crop yields. 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 testing laboratories are closing down.

Increasing demands for quality control from export markets, implementation of payments for environmental services, and environmental baselines to support policy formulation were never going to be
met by conventional laboratory methods. However, recent advances in infra-red spectroscopy\textsuperscript{16}, calibrated by conventional laboratory data offer reproducible measurements of various constituents of a wide range of materials in seconds - without tedious sample preparation (Shepherd & Walsh 2007, Terhoeven-Urselmans 2008). There is no need for costly laboratory facilities and exacting staff training so the cost is a few dollars per sample, compared with hundreds for conventional analyses. Potential applications include soil carbon, organic matter fractions, plant nutrients, salinity, heavy metals, clay mineralogy and some engineering characteristics; water quality; seed and crop tissue screening. Pending development of dependable field instruments, services can be provided by mobile IR spectroscopy units. There are caveats on extrapolations from proxies to inferred values of actual soil properties and from spot measurements across areas confidently considered to be of the same soil type, and from such inferences to actionable advice. However, the ability to acquire a high-density of measurements would be a step change in environmental management from detailed measurements on a few samples, extrapolation of results and reliance on expert opinion, to a focus on interpretation of measurements and interpolation of results.

3.4.6 Land resource information systems

If spatial data are made available in electronic digital form, anyone can use them, perhaps in novel ways (Fisher 2003). Nowadays, more and more spatial information is deployed within computer-based geographic information systems (GIS). As an extension of an effective planning department, and with its own dedicated staff, GIS can combine various layers of data (for instance land capability, land use, ownership, planning units and infrastructure) to reveal new information and depict it a way that decision-makers can grasp. For instance 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).

An early public information system still in operation was established in 1968 by the Texas Water Development Board to provide common access to natural resources and census data, digital and paper maps, and further information collected by state agencies and other organizations (http://www.tnris.org/). The first national natural resources information system was the Canada Land Data System, and CanSIS (http://sis.agr.gc.ca/cansis/) the first national soil information system - fully operational in the 1970s (Dumanski and others 1975) and a model for many that have followed. At the outset, it was championed by senior management in Agriculture Canada, ensuring that the technical staff had the resources to make it work. The web site provides information, national-scale web-maps, and a guide to more detailed printed maps and reports (and human assistance) serving policy-makers, planners, natural resources managers, farmers and growers, agronomists, engineers, and researchers. And, today, the USDA Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm) has 100 000 unique users and delivers 15 thousand customised soil survey reports every month. By contrast, the present state of the Australian Soil Resources Information System demonstrates how hard it is to meet the needs and aspirations of 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 as promised at the touch of a key. There are two issues: 1) 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 hosted by key institutions with good staff and facilities; 2) Data for different attributes and scales are rarely compatible, being derived from various sources and collected at different times and for different purposes.

\textsuperscript{16}In particular, diffuse reflectance spectroscopy within the near infrared and mid infrared wavelength range
Recently, 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 (Box 12), usually supported by outside money and technical expertise. In the Caribbean, the Global Environment Facility has funded sustainable land management 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, and all including a computerised Land Resources Information System.

**Box 12: Developing a land information system in Niue**

Land degradation is a big concern on the Pacific island of Niue as a consequence of shifting cultivation with much-reduced periods of bush fallow, extensive land clearance for cropping of taro for export, ploughing and reliance on agro-chemicals. Resolution of these issues will need discovery, testing and developing of profitable, sustainable land use and management practices in partnership between agronomists or experienced extension workers and farmer-leaders or innovators. However, UNDP (undated) noted ‘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’. And, indeed, there are good data going back to Captain Cook (1777) and the now-forgotten soil surveys by Wright (1949) and Wright and van Westerndorp (1965). UNDP supported a five-year (2006-2011) sustainable land management project which, amongst other things, has developed a Land Information System for managing land information data. We may hope, but must doubt, that UNDP’s main effort has been applied to practical development of profitable and sustainable land use.

A desk study of land information systems for the Pacific Islands Forum Secretariat (McIntyre 2008) notes some common shortcomings that 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 require 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. Experience has been gained in handling computerised 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).

### 3.4.7 Citizen science

The British Geological Survey has released an iPhone app called *mySoil* ([www.bgs.ac.uk/mysoil](http://www.bgs.ac.uk/mysoil)). Entry of a post code or GPS location brings up an interactive map with information on the local soil texture, thickness,
organic matter content, pH and other properties, data on average UK soil temperatures from the Met Office, and a unified Europe-wide soil map from the EU Joint Research Centre with information on soil texture, thickness, parent material and habitat. The composite information is of variable quality but it does enable free-lance professionals and citizen science to build up community-produced information to fill the gaps, correct the errors and add local detail to existing datasets. Similar links with existing and new land resources information systems offer the possibility of generating the detailed land resources information that is needed everywhere in the world, working within a framework of the best-available, professional survey data. Large-scale, up-to-date air photos would be an ideal base map for local surveys but, in their absence, Google Earth provides a publicly available base map and cartographic tools which are already used by private-sector soil surveys in support of precision farming.

‘O brave new world.’

Brave new world. Aldous Huxley 1932
Chapter 4

CONCLUSIONS

‘We must get surveyors and agronomists back on the ground. They must dig, auger, observe and experiment. They must design and analyse. And they must report. I see no alternative. If I am right, and this is the only way to get the information to plan development and increase production without degrading the...resource, then it is not a question of whether we can afford it: we cannot afford not to if we are to stay clear of the Malthusian precipice.’

Richard Webster 1997

Land resources on the edge of the Malthusian precipice?

4.1 Policy imperatives

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; but only recently have we appreciated the ecosystem services also provided by the land that underpin productive land use and urban communities.

Urgent demands for land resources information, mainly from governments, fostered a Golden Age of land resources surveys for a quarter century after the Second World War. Then governments lost faith in their ability to command and control, abdicated responsibility for land use and management, and turned to markets to deliver their aims - leaving land users to their own resources. At one level, they were right: the world has never been so rich or well fed. But the food system today is unsustainable. The green revolution that doubled or tripled crop yields in the years 1965-1980 depended on cheap fuel, fertilizers and irrigation applied to responsive new crop varieties. Fuel and fertilizer are no longer cheap; water resources are over-allocated in all the main food producing areas; the yield increases of the green revolution have tailed off - in some places they are decreasing; and both industrialised agriculture and unsupported subsistence farming are driving land degradation and climate change.

The need to deliver twice today’s production by 2050, arrest land degradation and cope with climate change, demands a new era of high farming - adapting operations to the diversity of the landscape and taking advantage of natural variation rather than ignoring it. At the same time, sustainable management of forests, rangelands, wetlands and barrens is needed to maintain essential environmental services. All this requires more-detailed land resources information than has yet been assembled. Rational development of towns, cities and infrastructure depends just as critically on land resources information - and the immediate costs of mistakes here are, if anything, greater.

4.2 The state of land resources information

The need to factor good intelligence into development policy, planning and management seems obvious - yet it 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 run down or dismembered. In most countries, fundamental data are
dispersed, fragmented and, for the most part, more than thirty years old. Millions of field observations and laboratory analyses have never been transferred to publicly-available databases and there is a general lack of detailed local information. The erosion of specialist skills within natural resources agencies and universities has created capacity gaps that will be hard to fill and, without a renewed cadre of experts, such data as we do have are drifting away from the status of live information to that of fragmentary historical documents.

Does it matter? During the green revolution, farmers across much of the developing world greatly increased crop production without making any use of formal land resources information; over the years, they adopted or, rather, adapted the green revolution package to their own land resources by trial and error. The parent of the groundbreaking IR8 rice was not invented by IRRI but spotted in his own field and planted out by a Chinese farmer. And 40 years of development of conservation agriculture, started by a group of Brazilian farmers, has been by peer-led adoption of what was found to work – again without reference to formal land resources information.

All this is true - but farmers’ experience (and engineer’s experience for that matter) holds only for continuation of existing practices. We argue that the present farming systems are unsustainable and that land resources survey, land evaluation and field experiments are needed (in Bangladesh and Brazil and elsewhere) for sustainable intensification, at the same time safeguarding the environment and adapting to climate change. More-detailed information is also needed in countries that already have large-scale commercial farming systems managed by business-like farmers who no longer have hands-on knowledge of what lies below ground. Without this information, change means trial-and-error all over again. There isn’t time. And the land degradation and flight from the land over the last quarter century should remind us of the costs of trial-and-error.

We can draw on many examples to demonstrate that good land resources information, combined with a good understanding of existing land use and the requirements of any proposed innovation, means quicker and safer uptake of new practices. The same applies to urban and infrastructure development. Moreover, many natural systems operate over hundreds of miles; their dynamics are not discernable by local observation, however perceptive; and their effective management needs a helping hand from science. China, Brazil and Korea are continuing to build up their knowledge of the land and the USA maintains substantial capacity but, for the most part, the information needed and the institutions that could deliver it no longer exist.

4.2 How to put things right

4.2.1 Push and pull agendas

The pre-requisites for good decisions about land resources are: first, reliable, up-to-date, spatial coverage of primary data and interpreted information - if this is held in an accessible GIS-based land information system, so much the better; secondly, a cadre of experts able to select and translate the data into directly usable advice; thirdly, effective active demand for this advice from decision-makers. Take away any one of these conditions and the others fall. We see from the case studies that atrophy of land resources information in the Age of Uncertainty was a consequence of loss of demand. Why demand fell away is an important question but there is no doubt that, without the pull of demand, pedlars of information are unlikely to prosper.

How to put things right? Shouting at decision-makers - telling them that they are doing a bad job or getting it wrong - doesn’t help. Without a strong pull in the shape of demand for natural resources information, pushing from the outside to introduce a different way of doing things is a difficult and, usually, fruitless
pursuit: far better to secure a pull by dialogue with decision-makers, to understand their needs and concerns, and explain how our own ideas and information might help. In Europe, the Soil Thematic Strategy (European Commission 2006a) was the outcome of such a dialogue. It called for a comprehensive approach to preserve soil functions on four fronts: awareness raising, research, integration of soil protection with other policies, and legislation. The first three have been implemented to some extent by EU institutions but hardly at all by member states. The proposed Soils Directive was blocked in the Council of Ministers; that was before the spike in world food prices and global financial upheaval - the reaction might be different today but that initiative was lost.

Payments for environmental services are a market-related alternative to legislation but hard-nosed investors will only pay for what can be measured. Any such mechanism depends on reliable, up-to-date information on the status and change of the specified resource or hazard – and this information cannot be turned on like a tap. Carbon trading was initiated under the Kyoto Protocol but remains small-scale; salt trading has been implemented in the Murray-Darling Basin in Australia; green water credits have been researched in several places -but not yet implemented anywhere.

4.2 Rebuilding commitment, knowledge and capacity

Public reaction to a new truth has three stages: ‘It’s not true’; ‘It’s against scripture’; and, finally, ‘We knew it all along’. Responsible natural resources policy depends on knowledge that enables progress from denial of the issues, to recognition and, finally, accepting ownership. In most places, no one and no institution is collecting and maintaining the required information - and the existing information is not fit for purpose.

There are several tracks that might be followed to rebuild commitment, knowledge and capacity. The path actually taken will depend on national and local circumstances but needs to take in:

- **Awareness-raising and education** to build public knowledge and ownership of the issues

- **Research** to understand the problems and find solutions. Governments, companies and communities need intelligence to determine the dimensions of policy and management issues, the adequacy of existing information, and what further information may be required - both new land resources surveys, practical ways of adding local knowledge to formal land resources information, and the know-how to linking land evaluation with implementation.

- **Community and industry participation** to share the load. We may draw upon the bumpy experiences of the regional institutions in Australia - established to get the right people working together; and the Comilla model in Bangladesh - helping farming communities to explore their own resources, systematise their own experience, identify their constraints and try out promising options. Once communities are well along this path, with a conscious and structured understanding of their own resources, they are in a position to demand and make use of professional land resources information.

- **A career structure for land resources specialists** who can translate data into directly usable advice. Across the western world, most of the cadre is pensioned off and universities and colleges no longer offer training in land resources survey and land use planning.

It will need a sea change in the policies of national governments to reinstate publicly-funded land resources surveys at the field scale needed for precision farming and community action. However, recent technical
advances make the necessary field work, laboratory analyses and data management a less daunting proposition than, say, it was a generation ago; and something like the British Geological Survey’s mySoil app can provide i-phone users with an interactive local map that summarises the present state of knowledge of the land. Anywhere in the world, such a link to the best available mapping would enable local professionals and citizen science to build up their own detailed information within and compatible with the formal framework. However, this new information will be lost again unless there is a requirement to archive it with a public institution responsible for maintenance and access to the data. Several countries manage mineral resources information in this way.

Facts don’t speak for themselves. Someone has to speak up for them and it helps to have access to the relevant decision-makers. Time and time again, we have seen progress 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 with the National Action Plan for Salinity and Water Quality in Australia; Premier Wen Jiabao persuading provincial administrations to fund multi-objective geochemical survey in China... And our champions need to be armed with a compelling analysis of alternative natural resources strategies, comparable with the Stern Report (Stern 2006, Hamilton Group 2009).

What will it cost and how long will it take to rebuild commitment to land resources, the knowledge base, and capacity for effective action? It may not be necessary to start from scratch; once government and industry know what they need, roles may be assigned to existing institutions with related expertise that can build capacity, broker relevant information and specify what further information may be required. Once there is demand, supply will follow but the dearth of experienced staff will require urgent attention. For the UK, the ongoing cost will be no more than is spent today by a 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
CASE STUDIES

1: 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 revolution; in Sub-Saharan Africa, 280 millions go hungry. 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 have 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 governments assign responsibilities to state and local authorities without providing the capacity or adequate funding, so devolved authorities resort to exploitation of natural resources and poverty forces local communities to follow suit
- Appointment or election of decision-makers and planners on grounds of politics rather than competence
- Corruption and mismanagement by bloated legislatures and 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 effective land use plans and the land resources information needed to make them, lack of land use and land capability databases and systems to monitor land degradation, and lack of quantitative environmental indicators related to land and water.

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

1.1: 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 people’s aspirations; 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 6), 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, the degrading areas suffered an average NPP loss of 29kgC/ha/yr. 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 so; 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.

**Figure 6:** South Africa – Proxy assessment of land degradation 1981-2006 (negative RUE-adjusted NDVI trend) (Bai & Dent 2007)

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**Natural resources issues**

There have been some advances in the collection and presentation of land resources information but there are critical gaps and the accessibility of extant information leaves a lot 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 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 greater impact on rural development. Land resources information is also needed and used at 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; and by NGOs and civil society. Their needs are many and various.

**Information providers**

**Topography and geology**

The Council for Geo-science (formerly the Geological Survey of South Africa) is responsible for mapping the country. Topographic maps are 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 20000 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](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 actually 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 called for the revival of 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 & 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 & 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 resolution for 1985-2003 and modelled NPP at 8km resolution 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 communal lands (former apartheid homelands) are a concern (Hoffman & Todd 2000, Hoffman & Ashwell 2001). Their big human and livestock populations are accompanied by overgrazing, soil erosion,
excessive wood harvesting and loss of palatable pasture species (Shackleton & others 2001) that are attributed to a combination of poverty and failure of regulation (Scholes & Biggs 2004) arising from both current social and economic changes and the legacy of apartheid (Dean & others 1996, Fox & Rowntree 2001, McCusker & Ramdzuli 2007). There is further concern that land redistribution programs might expose productive land to the same degradation; the example of neighbouring Zimbabwe is close to home. However, there is degradation in commercial farming areas too (Figure 6).

Water resources

The Dept of Water Affairs Directorate of Water Resources Information Management, is responsible for managing data for strategic and development planning of water resources, as well as international agreements. Data are or have been collected under assorted national monitoring programs and 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. In 2005, the Dept 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. 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 Department’s Annual Report for 2010-11, annual targets for hydrology and geo-hydrology monitoring were exceeded because of the response to drought and flood in the Eastern and Western Cape. However, 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 - which may indicate the perceived importance of good baseline data. There is no doubt that the country faces pressing land resources problems, not least 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 are administrators and politicians who appreciate the importance of land resources information and would make use of more-accessible information but there are many more who don’t see evidence-based decision making as an imperative.
1.2 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), 850000 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 of which comes from mining, which is now in Chinese hands.

Land resources surveys

Soil survey
(from Dalal-Clayton & Dent 2001 and Sokotela 2012)

Trapnell’s ground-breaking surveys of Northern Rhodesia (1937, 1943 and 1949) were well-thumbed by a generation of Agricultural Officers but not followed up save for the appointment, in 1954, of one soil surveyor based at the Dept Agriculture Mount Makalu Research Station. Ten years later, the Government of newly independent Zambia requested international assistance and FAO expert, Hugh Brammer, proposed a national soil survey unit. NORAD agreed to pay for expatriate surveyors, who began to arrive in 1973; while waiting for the NORAD surveyors to arrive, Brammer himself undertook several ad hoc surveys for soil and water conservations and completed a reconnaissance of the whole country. The UK Land Resources Division also undertook an extensive land systems survey in the north of the country (Mansfield & 1975/6).

From 1977, NORAD paid for the Zambia Soil Survey Unit (SSU) which became one of the most active survey organisations in Africa - securely funded, well equipped and able to undertake an extensive field program; several Zambian staff trained overseas. Development projects kept the Unit busy with ad hoc surveys for five years but an 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 and, 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 (Wood 1981).

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 and 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 conducting soil survey and land evaluation of farm blocks – one per province (between 1 5000 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.

**Geological survey**

In contrast to land use, forests and soil survey, geological surveys worldwide remain fully functional, well-equipped and resourced - particularly in countries where mining and oil extraction contribute significantly to the economy and government income. In Zambia, the Geological Survey Dept 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 a national map at scale 1:1million (Zambia Geosurvey 2011).

### 2: SOUTH AND EAST ASIA

#### 2.1: China

Area 3 700 593 sq miles (9584492 sq.km), Population 1 340 000 000 (2010 census)

*With Zhanguo Bai and Yunjin Wu*

**Context**

China supports 22 per cent of the world’s population upon only 7.2 per cent of the world’s arable land. Food security has always been precarious and, 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 substantial 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 conversion of arable, land degradation, water use and water resources protection, fertilizer-use, pollution of land and water, 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; land use planning has been strengthened by amendment to 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 the use of land 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. 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 the quality of their land, as determined by detailed soil survey information. Assignment of land for industrial development is increasingly by public calls for expressions of interest, competitive bidding and auction.

Even greater reforms are foreshadowed in the Decision of the Communist Party of China Central Committee on several important issues of comprehensively deepening reform, Communiqué of the Third Plenum of 18th Communist Party of China Central Committee: ‘The building of ecological civilization system will be accelerated; a system of compensation for the use of natural resources and the subsequent impact on the ecosystem will be established soon.’ For the first time, this draws a ‘red line’ for ecological protection and, under the theme of ‘eco-compensation and implementation’ considers payments for the use of resources and ecosystem services. China is setting itself up as an international role model.

**Land resources status and trends**

**Land use change**

To ensure food security, China tries to maintain at least 120 million ha of arable. Figures for 2007 were (in millions of ha) arable 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 shrunk 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, land destroyed by natural hazards (17 900ha) was half the previous year, while 25 400ha was assigned to habitat 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.

The 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 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 is projected to 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 & 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, especially flooding, cost billions of RMB yuan and are responsible for many hundreds, sometimes thousands of deaths every year. Responses include geo-engineering; training courses in rural geo-hazard prevention and control reaching nearly three million people in 10000 villages throughout the country; geo-hazard investigations in hill country and cities; flood monitoring and early warning and nationwide weather 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 by the end of 2007 some 1700 geo-hazard control projects, 1897 landslide monitoring and prevention stations and 160 000 mass-movement monitoring and interventions. 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 extent and economic impact of land degradation and more than any other 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 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 1991, Dregn 2002) although livelihoods in these areas were always precarious.

Figure 7: Trends in climate-adjusted net primary productivity in China, 1981-2006
(Bai & others 2013, calculated from NAASA GIMMS NDVI data Pinzon & others 2007)

Satellite measurements of climate-adjusted net primary productivity (NPP) over the period 1981-2006 (Figure 7) suggest that 24 per cent of the country has 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. China’s unprecedented growth of urban areas and infrastructure, over the same period, accounts for much of the decline of NPP in rapidly developing areas like the Yangtze and Pearl River deltas.

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**

**Topography**

Topographic survey is the responsibility of the State Bureau of Survey and Mapping. The Bureau provides topographic data for major engineering projects, construction of new towns and villages, land use planning, defence and security, boundary demarcation and base maps for various purposes; to date 602 000 topographic sheets, 164 000 geodetic survey points, 750 000 km² of aerial survey and 2.29 million km² of satellite imagery with an estimated societal value of 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 on-line geographic information security.

**Land resources**

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 by provincial, prefectural, and county agencies that make use of remote sensing, GIS and GPS. Land resources survey has been completed at scale 1:10 000 for 2 million km², at 1:50 000 for 620 000 km², and at 1:500 000 for 1.19 million km²; and a market survey at scale 1:10 000 has been completed for 99 800 km² (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.

MLR promulgates professional standards and has 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 arable land (excluding Tibet and Taiwan) at scale 1:2.5 million using an agricultural soil classification, and produced a National Soil Fertility Overview at scale 1:4 million based on farmers’ experience. This information was not fit for purpose - data on arable land were unreliable and there was little information on forest, pasture and wasteland; but, 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, which took 16 years and involved more than 84,000 scientists and managers, as well as supporting staff. Preliminary interpretation of air photos and satellite imagery provided a consistent basis for fieldwork and surveys began with detailed investigations at the county and township level, guided by uniform technical specifications. Soils were classified according to the Chinese system that embodies soil forming factors, processes and properties (Shi & others 2004); the maps show soil types, resource use, nutrient status, and zoning for improvement. In South China, most agricultural regions were mapped at scale 1:10 000 and 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 generalised as 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.

Work on a national soil map at scale 1:1 million 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 drawn up in 1990. Definitive compilation began in 1992 based on provincial soil maps, topographic maps and satellite images, also making extensive reference to records of soil, geology, forest distribution, land use, 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 with 909 soil mapping units, mostly families grouped into sub-groups (235), great groups (61) and orders (12), and 4 non-soil formations; the minimum delineation is 25 mm² (25 km² on the ground) for forest and pasture areas, 16 and 4 mm² (16 and 4 km² on the ground) in agricultural areas and regions of scientific interest. Further aggregation produced maps at scales 1:2.5 million and 1:4 million, the latter 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 according to their hierarchical classification, parent material, soil profile and thickness. Each typical soil profile description includes site and climatic data, natural vegetation or crops at the site, productivity, and field description of colour, texture, structure and rooting pattern. Analytical data include particle-size distribution, pH, organic matter, CEC, exchangeable bases, exchangeable H and Al, total N, P and K, and available P and K.

There is a 1:1 million digital soil map supporting research, education, national and regional agricultural production planning, water and forest resources, environment protection and ecological restoration (Shi & others 2011). Work continues on the associated soil database: province by province, 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 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.

The Chinese soil classification employs 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 from *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) on digital soil and land survey methods.

**Soil pollution**

Systematic data on soil-environmental quality is required to assess the type, extent and causes of pollution and the risk of contamination; develop remediation technologies; set national standards for the soil environment and establish regulations to control pollution. A nationwide soil pollution survey led by the Ministry of Environmental Protection from 2006-10 involved one thousand organisations and some 20 000 professional and technical personnel. Some 214 000 soil samples were taken for analysis of specific heavy metals, arsenic, organo-chlorine pesticides, polycyclic aromatic hydrocarbons, and phthalates. Outputs include evaluation, status and comparative analysis of soil-environmental quality, contamination, risk assessment of key areas, planning of remediation, comprehensive management of pilot areas, and establishment of a system of soil-environmental quality monitoring 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. 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 km², 1.6 million km² 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.

Following up issues identified in the survey, an eco-geochemical evaluation was made in the basins of the Yangtze and Yellow Rivers, the northeast plains, and coastal economic zone to appraise both soil fertility and heavy-metals pollution. Further 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.

**2.2: 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). Only 27 per cent of the country is cultivable and about 20 per cent is actually cultivated (Kenting Earth Sciences 1986). 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).

For all their importance, land resources are poorly managed. Food production is falling and 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 & 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**

**Topographic survey**

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 available in digital GIS format data on geodesy and topography, hydrography, administrative boundaries, transport infrastructure and utilities, built-up areas, land cover and designated areas (Chatakuli 2003, Sharma & Acharya 2004).

**Cadastre**

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.

**Land resources**

The 1974 assessment of development potential in the Nawalparasi area was the first integrated survey carried out by the British Land Resources Division (Berry & others 1974). Systematic land resources mapping was then undertaken between 1976 and 1984 under 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; 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). However, 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. There is a 1:250 000 Soil and Terrain database compiled by ISRIC in 2005 using the Kentings data and the SRTM DEM. Its existence is effectively unknown in-country but it is accessible through [http://www.isric.org/data/soil-and-terrain-database-nepal](http://www.isric.org/data/soil-and-terrain-database-nepal).
Soil Fertility Mapping

Strengthening of the Dept of Agriculture in 2004 upgraded the Soil Analysis and Service Section to a new Soil Management Directorate which has made annual budget allocations to prepare soil fertility maps for between one and four districts. The maps show the spatial distribution of NPK, organic matter and pH for cultivated lands only, although land systems are represented in the sampling design. Progress is limited by inadequate staff resources but, to date, 29 districts have been mapped (SMD 2013). There is no mechanism to manage or share this information but, once the soil fertility map of the country is complete, the Directorate plans to prepare (and implement) a comprehensive plan for soil use and management.

Forest Resources

Forest data are scattered across different organisations and have not been systematically updated. With Finnish assistance, a National Forest Inventory was accomplished by the Department of Forest Research and Survey using remote sensing and GIS technology, beginning in the early 1990s and completed in 1998. Comparison of the data with the 1976-84 Land Resource Mapping suggests a 2 per cent decrease in the total area of forest and scrub (DFRS 2002). The information was used in forest sector strategy and 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 every level and scale including, as well as conventional forest and tree characteristics, data for dead wood, biomass and soil carbon, biodiversity, and human impacts (Kandel 2011). Under a further bilateral agreement with Finland, 2010-2014, a National Forest Resource Assessment is under way to strengthen 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 organisations.

Use of land resources information

It is hard to judge what use is actually made of land resources information. Since 1956, Nepal has produced periodic five-year development plans (the tenth is now in effect) that 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 and the Government continues to seek bilateral and multilateral technical and financial support. However, 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 in such projects then find better prospects elsewhere.
3: AUSTRALIA

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

The driest continent

Australia stands out from other continents: by far the smallest, flattest, driest, least-fertile - but biologically astonishing. Until European settlement 250 years ago, it supported the fewest people but most the most distinct vegetable human societies. Still with relatively few people, Australia is a major exporter of primary products; as well as minerals, 60% of farm production (valued at $A23 billion in 2008/9) is exported (DAFF 2009). Growing global demand for primary products presents further opportunities but Australia will need to reallocate its resources to serve its own growing population and the country is uniquely exposed to climate change. Beyond food security, current policy priorities are to protect ecosystem services, improve water use and management, tackle the issues of crop nutrition and reliance on high-energy fertilizer, reduce greenhouse gas emissions, and store more carbon in the soil. (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 biggest river, the Murray, failed to reach the sea and water was cut off from long-established irrigation areas. The Australian Agriculture Assessment (NLWRA 2001a) highlights: extensive soils poor in organic matter, poorly structured and water-repellent – conditions made worse by agricultural practices; widespread soils with an infertile bleached underlying layer a clay pan that restricts drainage and rooting; 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 28% 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 the north, carry strongly weathered, nutrient-poor soils. Liming is an order of magnitude less than needed to remedy soil acidity so 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 increased salt concentrations in the streams; this trend will continue in a drying climate.

As a proxy measure of land degradation, Figure 8 shows negative trends in NDVI over the period 1981-2006. The affected area is almost 2 million km² (more than 6 per cent of the global degrading area), most conspicuously in the Tanami Desert and sub-tropical north but there is also significant degradation of rain-fed farmland across the western slopes of the Great Dividing Range and in Western Australia.

There have been management successes, such as maintaining a surface cover of trash under sugar cane but several recalcitrant issues stem from the attempt to adapt imported farming systems to the Australian landscape: 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 have evolved in response to local conditions - but this will require better land resources information and practitioners who can work across disciplines to develop and apply new farming systems.

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17 An ironic exception has been the non-adopting of regular liming of acidic soils – a practice adopted by farmers in Europe since the Agricultural Revolution in the 18th century (Wallerius 1761).
The Garnaut Climate Change Review (2007) noted the likelihood of 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 so that 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).

**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, Tropical Crops and Pasture and Land Use Research), 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. The States have struggled to provide adequate funds and although they remain the largest budget providers, there has been steady growth of Commonwealth funding and influence over natural resources management. In 1983, the National Soil Conservation Program allocated $20 million over four years; Commonwealth funding surged to $340 million 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 National Plan for Water Security $A10 billion in 2007.

Even when Commonwealth funds have been earmarked, getting things done across state boundaries requires hard bargaining. When the Commonwealth allocated unprecedented funds for a National Action Plan for Salinity and Water Quality in 2001, Premier Howard’s need to secure support from the States required disbursement of most of the money to state budgets - where it was dissipated without tangible impact on salinity. The subsequent National Plan for Water Security amounted to a Commonwealth takeover of water resources management, 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 being developed for investment in 14 industry and 7 cross-industry sectors, amounting to approximately $A1.6 billion annually (SRDE 2011).

Central direction has been accompanied by a focus on headline issues like salinity, drought and climate change - as opposed to maintaining a balanced capacity across the whole field of land resources. The last 20 years have also seen a shift of public funds to new regional institutions, positioned between local and state government, so as to respond to regional issues at an appropriate scale and to get the right people working together. This has diverted limited funds away from career scientists towards the new structures which lack coherent land resources information and the capacity to interpret and apply such information, and so 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)

**Climate and hydrology**

Weather, climate and hydrological services are provided by the Bureau of Meteorology; data from 4600 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° (about 5km) grid but its 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 strong demand from the military, shipping and aviation. In contrast, the history of hydrological data is one of stops and starts\(^\text{18}\), so policy and management depend

\(^{18}\)In 1887, the Royal Commission into water conservation in New South Wales noted: ‘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
heavily on modelling. 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. ABARES holds information on groundwater hydrology and salinity compiled from Commonwealth drilling programs and modelling, including trends and depths around high-value environmental and agricultural assets.

**Terrain**

State survey departments produce good topographic maps at various scales but for quantitative analysis of terrain and where various layers of data are to be combined, paper maps have been superseded by digital elevation models (DEM). DEMs for the whole country have progressed from 1/10th degree resolution in 1982 to 1 second (about 30m) 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).

DEM s 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 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 dwarfed by the multinational minerals industry that operates in the country, Geosciences Australia and the State geological surveys maintain systematic scientific data and provide advice to decision-makers. Digital geological information 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, three-dimensional detail 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. The 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 by most States in recent years. 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 Dept of Agriculture, Fisheries and Forestry and the Dept 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). 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, soils and land systems surveys were the main source of land-use information. 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 satellite AVHRR data combined with Australian Bureau of Statistics Agricultural Census data for farmland and extant data for other areas, mainly at scale 1:250 000.

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 by 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 noticed a stretch of dark, friable soil along the cliff top and, later, ploughed the first furrow in Victoria. It wasn’t long before Departments of Lands, Agriculture and Mines of the various Colonies began surveys for Settlement Boards at 40 chains 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 standardised information 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). These surveys were so well-received that in 1944 the Rural Reconstruction Committee recommended that all future irrigation schemes should be preceded by detailed soil surveys (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 began to recognise relationships between the various soils in particular landscapes. From detailed 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. Still 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 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 land systems 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 of the natural vegetation was intact. Rapid appraisals were made at low cost, since large areas were mapped with little fieldwork, 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 surveys can actually deliver. Emphasis changed to risk-avoidance and issues of the day that 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 1:375000, and the regional airborne geophysical surveys of salinity and water resources (Dent 2007); also the acid-sulphate risk mapping of coastal areas
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 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 fall short of minimum requirements (Figure 9). Old data are being flogged to death, revealing their limitations; as they are derived from project-specific studies for many and various purposes, they are hard to standardise and integrate for new applications.

**Figure 9a: Suggested level of soil mapping for Australia**

![Soil mapping levels for Australia](image)

**Figure 9b: Broad estimate of the extent to which current soil information coverage meets required coverage and resolution**

![Soil information coverage](image)

Apart from early irrigation schemes and the CSIRO land systems mapping, surveys have been undertaken by State and Territory agencies that never achieved coverage at the required scale before they were scaled back or discontinued. Only 30-40% of broad-acre cropland has even minimal 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.

Western Australia has correlated soil maps for 60% 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 1:250000 but with only rudimentary soil attribution. South Australia has soil landscapes mapped at 1:50 000 or 1:100 000 across all the southern cropland, recording a comprehensive set of soil attributes for the unmapped landscape components; and 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. 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. New South Wales and Queensland have challenging requirements of extensive high-resolution mapping that will need significant further surveys although 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. At the time of writing (July 2013), soil survey activities have been closed down in South Australia and New South Wales.

In the late 1990s, CSIRO tried unsuccessfully to model detailed soil distributions countrywide from point data and the digital terrain information available at the time; means were not available to integrate the legacy soil maps. The recent 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 at 90m resolution as part of GlobalSoilMap - but funding is not forthcoming.

**Australian Soil Resource Information Service**

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 shale gas exploitation. But even 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 has been lost. State agencies have applied information technology to make the most of their discontinuous data; the Australian Collaborative Land Evaluation Program tackled the mismatch of procedures and information content by agreeing national standards and 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) hosted by CSIRO (http://www.asris.csiro.au). An assessment of users’ requirements (Wood and Auricht 2011) indicated a need for:

- Information on key soil attributes like soil water, nutrients, toxicity, biology and carbon;
- Nationally consistent, authoritative, trusted, well-documented downloadable datasets;
- Links to comprehensive meta-data, including method descriptions, error and uncertainty and input source data – to enable users to assess the fitness-for-purpose of the data provided and refine them for their specific needs.

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 is struggling to maintain the system - let alone make it usable by policy makers and land managers.

**Ongoing needs**

The National Land and Water Resources Audit identified many issues of degradation of natural resources and remedial actions that should be taken urgently (NLWRA 2001a, b, c, 2002) and national, issue-based committees were set up to draw on expert assistance. The National Committee on Soils and Terrain (Campbell 2008) argued for a root-and-branch 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 century 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 (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
• 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 key national resource.
• 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, food and water security).
• 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. Of these, 128 were 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 loss of staff has continued as we see from the recent closure of soil survey activity in South Australia and New South Wales, historically the strongest states in this field, and 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 and the bunker mentality of the few remaining is a threat well-informed policy and its implementation. The National Soil R&D Strategy (Commonwealth of Australia 2014) builds on an overview of the natural resources information required in the national interest begun by the topic-specific working groups established more than a decade and it acknowledges the need for more investment, improved access to good information, sharing of knowledge and collaboration in the development of laboratories, long-term field sites and soil archives. Its proposals for building the needed skills and capacity in land resources management, operational from the first of April, include: establishing a committee for strategy implementation to report annually, topic-specific working groups, undertaking market research on user needs for land and soil information, a national skills audit, establishing a dispersed national soils archive, establishment of a professional Masters’ program in land resources and development of national soils curriculum.

Lessons for the future

1. Collection and analysis of land resources information is demand-driven. When there has been a felt need for information, funding has been provided and information delivered – but never quickly enough. The Golden Age of land resources surveys stemmed from 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 agencies to provide the information. But this demand has been fickle, depending on the commitment of
the government of the day and is sensitive to budgetary pressures - all the more acute because land resources information is perceived as enabling rather than immediately exploitable for profit.

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

3. Even so, if an issue assumes enough political importance, resources can be made available - even for data collection. But when an issue gets to the top of the list, the scientific 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 but soil scientists, geologists and hydro-geologists, atmospheric and hydro-chemists, agronomists and rangeland people all thought in their own boxes; in any case they hardly ever met. Political appreciation at Commonwealth level that new information from airborne geophysics was the key to cost-effective intervention brought an allocation of four million dollars out of the current year’s budget for airborne geophysical surveys; and another 75 million was earmarked for them under the National Action Plan. The first surveys knitted together strands from several disciplines, transformed our understanding of salinity and opened up the capacity for cost-effective interventions (Dent 2007) but, in the event, most of the initial four million dollars disappeared into a black hole in the Ministry and transfer of the main funds to the States brought in other agendas. Despite delivering on every technical promise, only three regional airborne geophysical surveys 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 that will be needed if market-based measures, such as water trading, are to be implemented.

4. Thanks to unstinting demand for mineral resources, Australia has weathered the global financial crisis better than most economies but there is no far-sighted strategy for renewable natural resources. 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. Whereas water policy is in crisis-management, a meaningful land and soil policy could still be prudent risk management - as well as going a long way towards redeeming the water balance - yet, there is no operational funding for the Australian Soil Resources Information System (ASRIS), identified as a key national resource by the National Committee on Soils and Terrain.
INSTITUTIONAL PROFILES

1: Hunting Technical Services (After Thompson and others 2011)

The history of Hunting Technical Services, a private company, 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. 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 vantage point of the surveyor from six foot above the ground to that of a hawk – and 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-Colombo 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 which was 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, defeated 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 in Nigeria (Parry and Trevett 1979) was the only large-scale application of this technique other than the Radambrazil mapping of the Amazon basin 1970/71; as in Brazil, the demand was political as much as a development-oriented, and the cost and technical difficulty meant 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 with 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 needs for land resources information were well specified and the information was immediately put to use in design and construction. Profitable follow-up work was secured by sensitive management, respecting the positions of the clients and independent-minded field scientists, and a commercial mindset that delivered the goods.

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, and by the following 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 the development of 500MW hydro-power from several dams and 900 000 acres of irrigation over 30 years (FAO/UNDP 1969). In 1977, Hunttings’ 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: 21000ha 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; it also created a database that eventually included more than 4000 independents that could be drawn upon when needed.

An early example of planning was the 1964-6 Jenqka Triangle Project in Malaya, in association with Tippets Abbot McCarthy Stratton, of New York (HTS and TAMS 1967). Hunttings 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.’19 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 already established by the national soil survey were adopted as mapping units and translated into land suitability for oil palm, 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

19Dick Kettlewell, quoted by Thompson & others 2011
and a volume of maps (Young 2007). Twenty five years on, a World Bank evaluation found 40 000ha of jungle cleared and 9200 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).

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 national self-sufficiency, border security and national integration – diverse objectives that were accorded more or less prominence with swings in the economic and political climate. 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 indispensable - 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.20

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 inextricably linked, and which 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 proved 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. The preferred approach to rural development became known as integrated rural development and this was taken up in HTS’s old stamping ground of Jebel Marra, continuing till 1995, and in a similar initiative in Southern Darfur from 1984 to 1988. The work spanned topographic mapping, resource surveys and 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 project 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 whole region’s slide into anarchy.

In development projects in the 1990s, monitoring and evaluation became de rigueur. One of the largest and most innovative was the evaluation of the impacts of all flood control and irrigation projects in Bangladesh as part of the Flood Action Plan, undertaken 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; the project involved disciplines from fisheries to

20See also case study of the Land Resources Development Centre
engineering to sociology and, as well as conventional questionnaires, 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. Hikes in the oil price in 1973 and 1979 transferred money for development into petrodollars - and governments lost confidence in their abilities to drive development through planning. Big projects depending on evaluation of natural resources dried up and HTS was a casualty.

HTS enjoyed the protection of the bigger Hunttings 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 similarly associated with larger and more diverse business interests but many were freelances that didn’t carry permanent staff and costly facilities - and were able to quote lower prices so that 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 its own Natural Resources Institute to do development work, the British government started giving budget support directly to the treasuries of developing countries to do with it what they would.

Training, informal or formal, had been a component of HTS projects since the early resource surveys. 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 management advisory roles, planning, operations and on-the-job training. For some years, HTS 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 allied 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 Natural Resources Institute 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.
2: The Land Resources Development Centre (after Makin, Bennet, Brunt & Griffin 2006)

The Land Resources Division, later the Land Resources Development Centre, was set up 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, imposing mighty overheads when the new mantra was competitiveness. 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 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 made up 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).

To start with, 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 the British Ambassador or High Commissioner and, from the early 80s, also by an expert Liaison Group of senior LRDC staff.

Land systems surveys

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. Land systems surveys relied on air photo interpretation to delineate the mapping units 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 a 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 in NE Nigeria (Bawden & Tuley 1966) and Lesotho (Bawden & Carroll 1968). LRD’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 the 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 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 LRD’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 data that he anticipated the sociologist would need. Land systems reports became more detailed and surveys were undertaken over several years: e.g. The Solomon Islands (Hansell & Wall 1974-7), northern Zambia (Mansfield & others 1975-6), central Nigeria (Wall & Hill 1978-82), and the whole of Indonesia (LRD 1985-89).

There was stark contrast between this leisurely progress and the rate of completion by commercial companies like HTS. However, LRD could argue that, compared with a commercial company bound by contract to inflexible terms of reference, an LRD team could recast its role to pursue potential development opportunities and the output might be only a short step from a rural development feasibility study. Certainly, LRD was able to apply 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 & 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. Later terms of reference implied that the host governments wanted to identify the entire range of development opportunities so LRD fielded multidisciplinary teams; however, final data from soil survey, groundwater bores and experimental sites inevitably arrived long after the economists had reached their conclusions. Early integrated surveys included Newalparasi, Nepal (Berry & others 1974), The Gambia Land Resources Study 1971-76 (Dunsmore & 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 & Dent (2001) commented:

‘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 unearthed 13 000ha of potential acid sulphate soils in the project area, and modelling with approximate data, killed the Barrage Project in 3 man-months. Its results were then confirmed by a further three man-years of surveys 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 projects21; later projects began with specific terms of reference relating to pre-defined development goals 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.

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 by remote sensing, identifying areas worthy of further investigation; then field 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 and the LRDC project manager, Ian Hill, was seconded to the Bank to help evaluate physical plans for settlement. LRDC was then 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, cost, urgency and lack of reliable land resources information dictated reconnaissance land system mapping from air photos and the newly available Landsat imagery. This eliminated the rugged, forested interior and the coastal peat swamps and sand terraces, leaving a 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). The maps were well received and the team went on to map the rest of Kalimantan, Sumatra and Irian Jaya. At this time, the team 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.

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21 Ivan Anderson, junior soil surveyor on The Gambia Land Resource Study, recounts his first job on arrival at the Dept Agriculture was clearing out thousands of 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 Dept 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 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 1:2.5 million 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 policy issues.

It was acknowledged that local capacity to make use of the maps and reports was limited; uniquely, 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, 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. In the event, only a few representative areas were examined: 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, the difficulty of assessing the depth of peat from air photos, or where the pattern of landforms was too intricate to map at 1: 250 000 (Brinn 1993). No one should have been surprised: 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).

**Tropical soils analysis**

Laboratory analysis has an equivocal reputation in land resources assessment; it represents exactitude but it’s hard to detect the contribution of these data to actual development. LRDC soil surveyors, working in places that had not been surveyed before, 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. At the time of the creation of NRI, the TSA laboratory was processing less than 200 samples a year 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) to form the Overseas Development Natural Resources Institute. In 1990, it became the Natural Resources Institute (NRI) and relocated to the grand and expensively refurbished former Royal Navy HQ at Chatham22. 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, the Natural Resources Management Dept comprised 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. Based on predictions of likely income from the Department for International Development (DFID, successor to ODA), the University expected NRI to be profitable. In the event, it was uncompetitive; DFID shunned natural resources projects and international donors shifted their attention to things like roads, sanitation, health and education. Over four years as part of 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 Dept, and a further 47 staff were axed in the same year.

But the name limps on.

3. ISRIC-World Soil Information

ISRIC 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, as the International Soil Reference and Information Centre, it was relocated in Wageningen but benevolently administered by the International Training Centre, in Enschede until 2002 when the Board opted for Foundation status.

At this time, ISRIC found itself the sole institute with a global mandate for land resources. FAO’s Soil Resources Conservation and Management Service had assumed this role during the Golden Age but was progressively gutted and filleted. The International Board for Soil Research and Management (IBSRAM), brainchild of the Canadian WO Bentley but established in Bangkok in 1985, focussed on soil management networks, e.g. for acid soils, shrink-swell soils in Africa, and land management problems in Pacific island countries. Field experiments were conducted within and by scientists belonging to the participating countries while IBSRAM advised, arranged coordination meetings and tried to highlight some wider land resources issues; but 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

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22 Staff who happened to be in Tolworth at the time of the move tried to preserve key archival data but a great deal was abandoned; and most of the material carried to Chatham was eventually dumped, first in the old machine shed and, subsequently, by barge into the North Sea.
desirable evolutionary trend\textsuperscript{23}; IBSRAM was wound up in 1999. So ISRIC assumed the roles of advocacy, documentation centre, and research: acting as anchorman in the 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 within the FAO program Land Degradation in Drylands (Bai & others 2007, 2008, 2009)
- Green Water Credits - creation of markets in water management services by farmers, supported by IFAD (\textit{inter alia} Dent and Kauffman 2007)
- Acting as catalyst in the GEF Global Carbon Benefits program
- Digital soil mapping - the Gates-funded GlobalSoilMap and the EU FP7-funded e-SOTER.

But the spirit has been lost and ISRIC has retreated into its founding role as a documentation centre. It is the custodian of the data for the 1:5 million scale FAO-Unesco Soil map of the World (1974-80) 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 documented soil profiles. The Soil Map of the World is still the only complete global coverage based on field survey; the latest Harmonised World Soil Database (FAO/IIASA/ISRIC/ISSCAS/JRC 2012), a 30 arc-second raster database combining updated regional and national soil data, still has large gaps filled by the FAO-Unesco map.

Since 1989, ISRIC has been the ICSU World Data Centre for Soils – one of 50 centres that scrutinise and archive biophysical data and make them publicly available. Apart from the FAO-Unesco map, no one else archived any current soils data but, as and when funding could be secured, ISRIC compiled existing soil surveys as soil and terrain (SOTER) databases at scales between 1:250 000 and 1:5 million with coverage of about half of the land surface.\textsuperscript{24} SOTER mapping units are land systems having distinctive patterns of landform, lithology and soils; each unit represents a unique combination of soils and terrain; the database consists of files for use in a relational database management system and a geographical information system (van Engelen and Wen 1995). The emergence of DEMs and digital soil mapping, brought together by e-SOTER, has driven a comprehensive revision of the methodology summarised by van Engelen (2012).

ISRIC also 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 freely accessible at http://www.isric.org/data/isric-wise-global-soil-profile-data-ver-31. These data are supplemented by a further, in-house set of 4 500 profiles. The data are compiled from various sources so 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 have varied 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 hoped for but adroit usage enables a wide range of environmental and agricultural applications at the continental scale (say 1:500 000).

ISRIC’s library and map collection was brought back from the brink over the period 2003-2009 and now comprises 15 000 documents, mainly hard-to-find grey literature of soil survey reports from developing countries, and 7 800 maps. In a joint venture with JRC, the map collection was scanned and is now


\textsuperscript{24}SOTER Latin America and the Caribbean scale 1:5 million (FAO/ISRIC) 1998; Central and Eastern Europe, scale 1:2.5 million (FAO/ISRIC 2003); Southern Africa scale 1:1 million (FAO/ISRIC 2003); and Central Africa scale 1:1 million (FAO/ISRIC 2007) are available on CD or from http://www.isric.org/projects/soi-and-terrain-database-soter-programme. Other organisations compiled databases for E and N Africa (FAO/IGADD 1998) and Northern Eurasia (FAO/IIASA 1999) but these lack soil profile data. There are national SOTER databases of Iran, Kenya, Nepal Nigeria, Senegal and The Gambia, and Uruguay. Independently, the Institute of Soil Science of the Chinese Academy of Sciences in Nanjing has compiled a China SOTER at scale 1:1 million (Zhang and Zhao 2008).
available as DVDs and on-line as the European Digital Archive of Soil Maps (Selvaradjou and others 2005, http://eusoils.jrc.ec.europa.eu/ESDB_Archive, though still lacking metadata. To date, one third of the documents have been scanned and are accessible at http://library.wur.nl/isric/.

The current focus is the World Soil Information Service—a centralised database to facilitate on-line access to all ISRIC data in a uniform format and to established international standards (Batjes and others 2011). Multilingual metadata are supplied on-line (http://www.isric.org/data/metadata-service) and there is partial global coverage of gridded 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. At this time its compliment was 12 scientists and 6 support staff with 6 scholars and guest researchers.

4. 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 land resources (soils, rangeland and forests) in the contexts of their landscapes, ecosystems and management. For many countries, these are the only detailed studies of natural resources and their potential use: their retention and maintenance deserve serious attention - especially information in the grey literature of short print-runs and documents held in unstable parts of the world.

WOSSAC was launched in 2004 as an initiative of the British Society of Soil Science to archive irreplaceable land resources reports and maps that were produced, mostly, by British surveyors, departments and companies in overseas territories. Its tasks are to maintain overseas soil survey materials and make them widely available by entering them into a modern 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 the 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 UK 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, wholly by donation; the largest single acquisition has been the entire collection of the former Hunting Technical Services. Archiving and scanning the variety of map sheets and reports, air photos and satellite imagery on paper, film and in digital forms, photos, microfiche and 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 23 000 items from 293 territories, and dating from 1909, have been catalogued and shelved. 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/archive/index.cfm.
Transfer of all the data to electronic format is a meticulous process that has to be externally funded. However, a very modest outlay unlocks the value of 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). WOSSAC depends on the brigade of pensioned-off scientists for material donations, cataloguing and maintenance; no support has been forthcoming from DFID, successor to the Ministry of Overseas Development that commissioned most of the original surveys, or from any other UK government source.

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 international network of archives. An earlier proposal by ISRIC 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 former Soil Survey of Scotland (held by the Hutton Institute, formerly the Macaulay Land Use Research Institute in Aberdeen). ISRIC’s collection is accessible through http://eusoils.jrc.ec.europa.eu/ESDB_Archive, FAO’s at http://www.fao.org/geonetwork/srv/en/main/home, and WOSSAC’s index at http://www.wossac.com/archive/index.cfm.

Archival information has been called upon for disaster relief, development planning and academic research – but nothing like enough simply because it is not known about. And even if preserved, the material 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. The need for champions is now urgent.

‘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 the availability and use of LR information in planning and decision-making.

(A) Political context and participants

Does the political context encourage and enable (or inhibit) access to and use of 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? What are the opportunities for public debate in the media or other forums? To what extent can those outside of the elite circle express their preferences?
  - 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 under consideration? 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 that affect this?

- Who has credibility in policy debates?
  - How do the interests of the participants 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?
  - How do the interests of media organisations affect what they report, and how knowledge is translated to policy?
  - Is it clear how participants’ values, beliefs and ideologies shape the coalitions built around an issue?
- Which participants are seen as credible experts on an issue? What does this mean for those excluded?
- Are there particular disciplines (technical, economic or social science) that are currently more credible than others in policy-making? How does this affect the policy-making process?

(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?

- What kinds of LR information are used in policy debates? Considering research information, citizen knowledge and practical experience, is any one of these dominant?
  - Is there a dominant narrative on agricultural development/intensification or environmental management? Are particular kinds of knowledge or information embedded in the policy-making and decision-making process so that they shape planning and decisions?
  - Do central and local policy-making or planning processes use different types of knowledge/information? What dangers might be associated with failure to recognise 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 with 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 particular issues e.g. sustainable agricultural intensification?
  - Which focus on engaging: helping policy-makers and planners frame issues inclusively by 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?
• What drives or enables the use and consideration of LR information in planning and decision-making?

• Do you consider that there is an adequate basis of LR facts on which to take 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?

• If LR information is not used or little used, why is this? Are there particular challenges or constraints 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 decision makers who 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 and planning, what data are needed, at what scale or precision, and in what 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 in-country capacity to generate NR information increased or diminished (since when and how)?
  - Have some organisations closed down or ceased effective operations?
  - Have others expanded their work or new ones been established?

• Is high-level training available in the country on LR management and gathering/evaluating LR 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)?
- 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 on LR-related issues?

How was the LR information incorporated in the planning or decision-making process?
- At what stage (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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Meeting the need for land resources information in the 21st century – or not

Sustainable use and management of land resources depends on good intelligence about their location, their condition and how this 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 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.

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, and assemble what is needed now, has been pensioned off. There are several paths that might be followed to put things right, depending on local and national circumstances but the longer the delay, the harder it will be.