FIG REPORT

FIG PUBLICATION NO 65

The Surveyor's Role in Monitoring, Mitigating, and Adapting to Climate Change



FIG Task Force on Surveyors and Climate Change

INTERNATIONAL FEDERATION OF SURVEYORS (FIG)

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Published in English

Copenhagen, Denmark

ISSN 1018-6530 (printed)
ISSN 2311-8423 (pdf)
ISBN 978-87-92853-26-4 (printed)
ISBN 978-87-92853-27-1 (pdf)

Published by
International Federation of Surveyors (FIG)

Front cover photos: left and right ©Paul van der Molen,
middle: ©School of Surveying, University of Otago
Back cover photo: ©School of Surveying, University of Otago

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Layout: Lagarto

Printer: 2014 Printservice Oy, Helsinki, Finland

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FOREWORD

This publication is the result of extensive debates, discussions, and presentations by the FIG Task Force on Surveyors and Climate Change over the past three years. The Task Force was established at FIG's Working Week in Marrakech, Morocco, in May 2011, to facilitate the work of the international surveying community in deliberating and better understanding how the surveying profession could contribute and assist the global community in measuring and monitoring climate change with its sciences, technologies, professional knowledge, and practices. The Task Force was chaired by Emeritus Professor John Hannah, New Zealand Institute of Surveyors and University of Otago. Its members, with their diverse backgrounds, experiences and expertise, were drawn from the global community of professional surveyors.

While individual surveyors have had a substantial involvement in climate change studies for almost three decades, it wasn't until 2002 that climate change issues became a formal part of the deliberations within the International Federation of Surveyors (FIG). The initial emphasis was on climate change and sustainable development – an emphasis that lead to a number of FIG publications and declarations. These were then followed by a series of initiatives that were substantially focused on how the coastal and marine environment should be managed in the light of likely future climate change. In 2008, an FIG working group was formed to investigate spatial planning in coastal regions. This working group, in producing its report in 2010, noted that from a surveyor's perspective climate change issues were not restricted to the coastal zone alone, but rather were diverse and cut across many other dimensions of the surveyors' professional activities.

The FIG Task Force on Surveyors and Climate Change set out both to explore and report on where and how surveyors could assist the global community in measuring and monitoring climate change, and also to elaborate on the part that they could play in adapting to climate change and helping to mitigate its impacts.

This publication provides a detailed summary of how the professional skills of the surveyor can be leveraged to help the global community as it grapples with the climate change issue. In reading the document it becomes clear that in many regards surveyors are not only the custodians of enabling technologies that are critically important to understanding climate change impacts, but that by virtue of their multi-disciplinary skills, they provide the bridge across the divide that can often exist between those who work in the natural sciences versus those working in the social sciences. It is thus a document that covers a broad spectrum of thoughts and practice, bringing about the convergence of the spatial and societal aspects of climate change.

The efforts of the Task Force are to be applauded and appreciated. We acknowledge the efforts and contributions of the authors in providing such a comprehensive document. It is our hope that it will not only spur surveyors on to a greater contribution to climate change studies, but that it will also alert global agencies as to the knowledge and resources that the surveying profession can bring to the table as climate change policy responses are developed.

John Hannah
Chair, FIG Task Force on Surveyors
and Climate Change

CheeHai Teo
FIG President (2011–2014)

EXECUTIVE SUMMARY

The surveyor is a practical, pragmatic, people-centric professional person, skilled in spatial measurement, able to represent, interpret and analyse spatial information, highly knowledgeable in the administration and governance of rights to the land and sea, and capable of planning for the development and use of land resources. It is this unique combination of skills that allows the surveyor to not only collect and analyse data vital to understanding the impacts of climate change, but also to grasp many of the complex human, political and physical interactions that arise in dealing with climate change issues.

Understanding the full extent of the complex interactions that are part of climate change science requires not just ad hoc monitoring of the earth, but rather integrated earth measurement and monitoring systems, many of which are satellite based. These data include radar altimetry, gravity, light detection and ranging (LiDAR), as well as sensors that use reflected or back-scattered sunlight as their radiation source. Such data can be used not only to provide detailed information about the terrain, land use patterns, water storage, ice mass balance and a host of other useful inputs which, when used together, provide a detailed picture of earth system change, but also to assist with emergency response and recovery operations after natural disasters. However, in order for this data to be correctly interpreted and integrated, it is essential that it not only be time tagged but also given well defined coordinates in a known reference system. Surveyors not only help define these coordinates and the reference systems that produce them but also help design and use the software tools that support the subsequent analyses of the resulting spatial data.

Some years ago the surveying profession recognised that its blend of professional skills offered a unique platform from which it could help the global community as it grappled with both climate change and a wider group of environmental issues. In 2011, following a series of earlier reports, the FIG formally established a Climate Change Task Force. This publication, which reflects the primary output from the task force, gives a detailed and comprehensive analysis of the many ways that surveyors can partner with global and regional organisations, and States, in confronting and responding to the climate change challenge.

Facing the Climate Change Challenge

Climate change presents challenges across a broad spectrum of human activities. In this regard, the surveyor's skills have particular application in the following areas.

1. **The design of urban communities and urban settlements.** Being the home of the largest part of the world's population, it is in the urban setting that the impact of climate change is likely to be the most acute. The surveyor is both the custodian and a user of the digital tools and the digital databases used in urban planning. These allow the surveyor to analyse planning options and make policy decisions. Nowhere is this more apparent than in developing countries where security of land tenure may be poor and where rapid urbanisation in disaster prone areas leaves people subject to disaster risk with subsequent loss of livelihood. Many urban dwellers live in poor quality homes on informally occupied or subdivided land with little or no protection against climate related disaster events. The surveyor, being skilled in the definition of land boundaries and having knowledge of the

associated tenure rights (whether formal or informal), can integrate information with climate resilient urban design processes, thus vastly improving outcomes for many of the world's disadvantaged peoples.

2. **The administration and use of rural areas.** Land use is responsible for more than 30% of all greenhouse gas emissions. Changes in land use (such as re-forestation) can thus have special importance in mitigating climate change both by lowering emissions and by removing such gases from the atmosphere. Additionally, many of the world's farmers are smallholders and pastoralists who are being increasingly affected by changing climate patterns. As they adapt there will be changes to land use as well as livelihoods. Climate-related migration will become a significant issue.

   Many of the strategies suggested for land use change not only require institutional platforms to promote sustainable land use planning but, just as importantly, a clear allocation of property rights that provide security of tenure. Such activities lie at the heart of the surveyor's professional skills. With land parcels and their associated rights fully integrated into land use data bases, governments should incrementally be able to improve tenure security and controls on poor or inappropriate land use.

3. **The management of peri-urban areas.** Peri-urban areas, which are found at the interface between city and country where urban and rural uses of land mix, and often clash, are likely to be affected by climate change migration. In developed countries these areas are generally managed intensively so as to prevent urban sprawl and protect agricultural land use. In developing countries they tend to be areas whose land-use changes rapidly from rural to semi-urban in relatively short timeframes, as people and cities respond to urban expansion or migration pressures. In the absence of long-term policy and planning, and as climate related disasters increasingly afflict agricultural land, people will tend to migrate to peri-urban lands, thus creating a new suite of problems. To what extent will unplanned urban encroachment be allowed versus the development of planned urban areas? How will those with existing land rights be treated? What land-rights, if any, will accrue to new occupants of such areas? Where will new infrastructure be located? These are questions which the skills of a surveyor are needed to help resolve.

4. **The management of the coastal zone.** The land-sea interface is the home of an increasing number of activities, rights and interests, thus rendering it one of the most complex areas of management. It is here that sea level rise will have its greatest impact. It is estimated that 10% of the world's population live in coastal zone areas that are less than 10 meters above mean sea level. Due to high population densities, shortage of land, and lack of alternatives, retreat in the face of both sea level rise, and an increase in the frequency and severity of storms, is exceedingly difficult. These issues are particularly applicable to Small Island Developing States (SIDS) where there is only limited institutional capacity to adapt. Improving the tenure security of people living on informal tenures (informal settlements, customary land, tenants and renters), can improve their resilience to natural disasters and other climate-related impacts. This is where the surveyor's experience, knowledge and skills can be of particular help.

5. **The use of forest resources.** Land use change, predominantly stemming from the conversion of forests to agriculture, is a large contributor to carbon emissions.

Unspecified property rights over forest areas, combined with insecure tenure and the allocation of forest land to commercial users by governments, have led to both widespread deforestation and the conversion of forest land to other uses. Such activities not only undermine incentives to improve land productivity and conserve forests but also lead to dispossession of land for indigenous peoples and forest dwellers.

In order to help overcome such problems, the UN has devised a programme to reduce greenhouse gas emissions from deforestation and forest degradation (REDD and REDD+). Protection of existing ownership and use rights over the land, natural resources, and the carbon sequestered are critical elements in the success of these initiatives. Surveyors are helping with tenure regularization for existing forest dwellers, and with collective titling for indigenous groups.

6. **The establishment of carbon credit markets.** Articles 6, 12 and 17 of the Kyoto Protocol establish a market for the trading of greenhouse gas 'assigned emission units'. Carbon trading takes place both at the Chicago Climate Exchange and in Europe. Apart from this 'compliance' market a voluntary retail offset market has also developed. At issue is the question as to whether or not an voluntary emission right creates a property right. Are carbon credit units financial products or property rights? If property rights, then the surveyor has an important role to play in recording these rights.

7. **The development of large scale agriculture.** Biofuel production, as a substitute for fossil fuels, has the potential to expand rapidly. This will result in greater competition for land access resulting in a need for better governance of land and resources. Here again secure property rights, transparent processes and a legal framework to enforce such rights for both investors and local land right holders are crucial preconditions if necessary investment is to occur. Additionally, however, the surveyor is able to use a combination of analysis and precise measurement technology [Geographic Information Systems (GIS) and Global Positioning Systems (GPS)] to assist in both defining agricultural management zones and in the optimal spreading of seeds, biological control agents and fertilisers.

8. **The development and use of water resources.** Climate change will have significant consequences on the hydrological cycle, and will pose risks to drinking water supplies. The growing pressure for access and rights to use the world's freshwater supplies highlight the need to have well defined water boundaries and usage agreements between countries, provinces and neighbouring landowners. Here the surveyor plays a critical role, not only in defining and mapping the spatial extent of such resources, but also in determining the spatial extent of their associated covenants and agreements. Furthermore, when it comes to constructing the infrastructure required to conserve and deliver water to where it is needed (e.g., dams, canals and pipelines) it is the surveyor who provides the precise measurement data needed to ensure the success of such projects.

9. **The construction of physical infrastructure.** Climate change has the potential to impact significantly on the integrity and reliability of physical infrastructure such as pipelines, electricity grids and transportation networks. Not only is spending on the world's basic infrastructure in severe deficit (currently amounting to $2.7 trillion/year when it ought to be $3.7 trillion/year), but the impacts of climate change are likely to exacerbate the problems that already exist. Much of this infrastructure

is aged and has not been designed for increasingly severe weather events. Furthermore, as climate migration occurs, there will be a commensurate need for the construction of new infrastructure where new settlement occurs. The construction of the engineering infrastructure used to meet these human needs require precise spatial positioning – a function that is solely the domain of the surveyor. The spatial definition of the land, its acquisition, and the easements necessary to provide legal security for such infrastructure, is again the domain of the surveyor.

10. **The use and conservation of energy.** $CO_{2,}$ arising from fossil fuel contributes almost 60% of anthropogenic greenhouse gas emissions. Strategies for the mitigation of CO_2 emissions include improving energy efficiency, conservation, the use of renewable energy resources, and the clean use of fossil fuels. Building orientation and design (essential elements in energy efficiency) can be improved – these being influenced by the shape and orientation of the underlying land allotments defined by surveyors. Heat leakage in buildings can be determined by using infrared aerial photography, and small scale generation (rooftop solar panels) improved. This can be done by building 3D models of cities using LiDAR scanning technology. This gives the surveyor the opportunity to define the orientation and surface of individual rooftops and shadow effects, showing the most favourable spots for solar panels. In addition, the surveyor's data integration, spatial planning, and measurement skills are necessary elements when constructing large scale facilities for renewable energy generation or the storage of CO_2.

11. **The spread of disease.** Climate change is having an increasing effect on the spread of diseases that not only affect humans and animals but also the general ecological environment. The surveyor has both the enabling technologies that allow the spread of diseases to be tracked and also the GIS tools that allow various spatially referenced databases (e.g., topography, water bodies, insect or animal locations) to be integrated with statistical and meteorological models thus allowing the prediction of future infestation or spread.

Surveyors' Response to the Climate Change Challenge

As humanity seeks to respond to the climate change challenge, and as it considers this broad spectrum of sectors where the surveyor's core skills can be leveraged, several common themes emerge.

Land administration systems. There is an urgent need for cadastral, land tenure, and land administration systems that fully reflect property rights and give tenure security to all legitimate landholder. In the first instance, these systems need to be accessible and able to be integrated with other land use and climate risk data so that climate change mitigation and adaptation strategies can encompass the spatial extent and rights of land owners and land occupiers. In addition, 'unbundled' property rights also need to be considered so that carbon credit titles, for example, can be registered and separated in land administration systems. Such developments as these are crucial if the climate related land use changes that will inevitably occur are to work to the benefit of the human race. Surveyors are not only developing "fit-for-purpose" approaches that are aimed at all tenures along a continuum of land rights, but they are also developing formal land administration systems to help with the demarcation of boundaries, cadastral and participatory mapping of social tenures, and with the recording of rights.

Spatial monitoring and measuring. Precise spatial measurement, which is the most traditional and best known skill of the surveyor, assists not only in monitoring the impacts of climate change but is also an essential element in adaptation strategies. For example, sea level change analyses require the precise spatial monitoring of tide gauges, using both conventional levelling techniques and GPS positioning. Land use decisions and erosion control are typically based upon detailed topographic mapping that may come from conventional land surveying techniques, or from laser scanning, or from digital image analysis. Precision agriculture (an important technique for increasing crop yields) relies upon GPS measurement technology. The construction of the new engineering infrastructure needed to support climate change adaptation requires the use of levelling, total station, and GPS technologies.

Spatial information management. The development of digital land related databases not only involves the comprehensive collection of relevant data, but also its integration into a common coordinate framework. This integration then needs to extend to the integration of social, economic, environmental and geographical factors so as to allow data mining, interpretation, and visualisation of different climate change mitigation and adaptation strategies. These design and integration functions can be undertaken by the surveyor.

Adaptation and disaster risk management. A range of adaptation strategies can be embedded into a land administration system so as to control the occupation and use of land and protect the vulnerable. Furthermore, disaster risk management and climate change proofing are core adaptation strategies for the urban environment. The identification of land suitable for the resettlement of climate refugees, the provision of secure land rights, and then the development of the necessary infrastructure are all essential tasks that can be undertaken by a surveyor.

Land-use planning. Long term spatial planning is an essential part of greenhouse gas emissions reductions. In areas with high levels of land administration capacity (typically the developed world), energy conservation is being achieved through improved design processes. In areas with low levels of land administration capacity, poor records, limited enforcement of land use policies, and poorly regulated land markets, the challenge is to find innovative ways for undertaking necessary land use planning.

It is clear that in many regards, surveyors are the custodians of enabling technologies and systems that are critically important to the future of the human race. Surveyors provide relevant geographic information for early warning and climate-related mapping, secure land and natural resource tenure systems to reduce vulnerability to disasters, and systems for managing urban growth and the use of land. In this way the surveyor's work supports climate change adaptation and mitigation, as well as social justice, economic growth, and environmental sustainability. However, surveyors recognise that the depth and breadth of the issues involved in climate change studies (whether scientific, social, political, or environmental), are of sufficient complexity that interdisciplinary cooperation is an essential prerequisite to finding robust solutions. Furthermore, partnerships at local, regional, national and international levels are essential if integrated, whole of community solutions are to be found. Surveyors, as land professionals, are committed to partnering with communities, professional groups, government agencies and global agencies in order to deliver these solutions.

1 INTRODUCTION

1.1 Overview

The global scientific community has a clear consensus view that the earth's climate system is being impacted by human influence (IPCC, 2013). However, the full extent to which climate might change in the future remains unclear. Climate models produce a wide range of possible outcomes depending upon the various forcing factors used – factors that in turn depend upon assumptions relating to industrial growth, greenhouse gas emissions, deforestation, the impact of clouds, and human response (amongst other things). Many physical variables and climate related changes can be measured and/or detected. Such measurements are used to establish the quantum of change, to tune climate models and to verify model outcomes. Once a quantum of change has been estimated, the challenge then becomes one finding mechanisms for mitigation or adaptation.

Beyond being subject to the effects of climate change, what role can surveyors play in its detection, adaptation and mitigation? Indeed, what do surveyors actually do? Do their skills and training provide some benefit to the global community as it grapples with these complex issues?

It is the intent of this report not only to answer the above questions but also to provide an insight as to how the surveying profession might be able to work with other global agencies in seeking to better quantify and understand the impacts of climate change.

1.2 The Function of the Surveyor

The professional skills that form an essential part of the surveyor's tool kit are not well understood, though they are diverse, varied and valuable. The International Federation of Surveyors (FIG) defines a surveyor as a person with the, "*academic qualifications and the technical expertise to conduct one or more of the following activities:*

1. To determine, measure and represent land, three-dimensional objects, point-fields and trajectories;
2. To assemble and interpret land and geographically related information,
3. To use that information for the planning and efficient administration of the land, the sea and any structures thereon; and,
4. To conduct research into the above practices and to develop them" (FIG, 2004[a]).

While these are very broad statements of capability, they give rise to a practical, pragmatic professional person who understands spatial measurement, who can represent and interpret spatial information, who is highly skilled in the administration and governance of rights to the land and sea, and who is capable of planning for the development and use of land resources (Hannah, 2013). Such a person is also able to take a wide variety of spatial measurement data, transform it into some common reference system and then integrate it into a data analysis platform. This platform then becomes a powerful tool that surveyors (and others) can use for assessing the likely impacts of climate change on global communities and in so doing support the development of the adaptation and mitigation policies needed to protect those communities.

It is this combination of skills that allows the surveyor to not only collect and analyse vital data about climate change that impacts our planet, but also to grasp many of the complex interactions that arise in dealing with the climate change challenge. Enemark (2011), for example, notes that surveyors as land professionals are able to make a valuable contribution to:

- Designing and monitoring earth observation systems related to climate change
- Building data modelling systems for managing spatial data related to climate change
- Incorporating climate change into current land policies and regulations
- Identifying hazard prone areas (arising from sea level rise, drought, flooding, fires, etc.)
- Introducing carbon footprint assessments in relation to land use developments
- Controlling building standards and emissions in relation to climate change
- Improving the resilience of existing ecosystems vulnerable to climate change
- Devising and managing transparent systems related to land tenure, land value, land use, and land development – all by using good governance principles
- Advocating and leading policy discussions with politicians, NGO's and civil society.

This is illustrated by events in Germany where the three national geodetic associations produced a Policy Paper named "Geodesists and the Energy Turnaround" (IGG 2014). The paper illustrates the broad range of geodetic knowledge and skills that can help in making the shift towards renewable energy come true. The three associations encourage political, administrative and economic decision-makers to draw upon surveyors' expertise when taking decisions and implementing measures with regard to new energy policies (cf. Friesecke 2014).

1.3 The Context for FIG Involvement in Climate Change Issues

The depth and breadth of the issues involved in climate change studies whether scientific, social, political, or environmental are of sufficient complexity that interdisciplinary cooperation is an essential prerequisite to finding robust solutions (Baerwald, 2010). Interdisciplinary approaches improve communication, fill knowledge gaps, and provide vastly improved perspectives on issues that require resolution. This, in turn, leads to better policy outcomes and improved mitigation and adaptation procedures. However, and despite the clear benefits of such approaches, collaborations amongst scientists from the natural and social sciences remain relatively uncommon (Gornish et al., 2013). Surveying, as a discipline, bridges this divide and thus surveyors should be logical participants in contributing not only to the assessment of climate change, but also developing adaptation and mitigation policies.

While individual members of the FIG have had a substantial involvement in climate change studies for over two decades (e.g., Hannah, 1990), it was in 2002 that climate change became an important issue on the FIG agenda. Between 2002 and 2006, the focus was on climate change and sustainable development. In 2002, FIG published its statement on spatial information for sustainable development (FIG, 2002[a]) and in the same year best practice guidelines for land information management for the sustainable development of cities (FIG, 2002[b]). These publications paved the way for its Marrakech Declaration in 2004 (FIG, 2004[b]). The focus of this declaration was on the urban-rural interrelationships necessary for sustainable environments.

Following the Marrakech Declaration, a cross-commission working group was set-up to investigate sustainable ways of managing the coastal and marine environment in the face of climate change. The output of this working group was published in 2006 (FIG, 2006[a]). Some of the issues identified in this publication led to further investigation which brought about the FIG Costa Rica Declaration in 2008 (FIG, 2008) – a declaration that focused on the effects of climate change on the land-sea interface. Following the Costa Rica Declaration, a working group was formed to investigate spatial planning in coastal regions. This working group, in producing its report in 2010 (FIG, 2010[a]), noted that from a surveyor's perspective climate change problems were not restricted to the coastal zone alone, but rather were diverse and cut across many other dimensions of the surveyors' professional activities. They therefore recommended that FIG should establish a cross-commission task-force to develop holistic and concise policy guidance on climate change adaptation for its members. This recommendation led to the formation of a Climate Change Task Force in 2011 – a task force that would report back to the FIG General assembly in 2014.

1.4 The Outline of this Publication

This publication outlines the conclusions that the task force reached as it considered the work of the surveyor in relation to climate change.

The publication begins by explaining how the professional knowledge and experience of the surveyor can be used to meet some of the needs of the human community as it seeks to quantify the extent of climate change, and to understand some of its impacts. Recognising that surveyors' core skills lie not only in their ability to measure and place objects in the spatial context but also in an intimate understanding of cadastre and land administration, the publication (in Chapter 3) then links these skills to the role the surveyor can play in helping communities to mitigate climate change and to adapt to its impacts. In Chapter 4, it extends this discussion to policy and governance issues.

Chapter 5 becomes the heart of the publication as these earlier discussion are drawn together to outline specifically how surveyors can apply their skills to help the global community. Some practical examples of such work are given in Chapter 6. Finally, Chapter 7 presents some suggestions as to where and how surveyors can build partnerships with other global organisations so as to improve the future of global communities as we all grapple with climate change issues.

2 UNDERSTANDING CLIMATE CHANGE

Changes in the climate system, generally consisting of warming, have been observed on a global scale for more than 100 years. The atmosphere and oceans have warmed, the volume of snow and ice has diminished, sea level has risen and the concentrations of greenhouse gases have increased (IPCC, 2013). Indeed, some of these changes are accelerating and are now probably irreversible (Lenaerts et al., 2013).

Climate change is mainly driven by the volume of greenhouse gases, aerosols, and by changes in solar irradiance. The largest contribution is thought to be caused by the increase in the atmospheric concentration of carbon dioxide (CO_2). It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. Even if anthropogenic emissions of CO_2 were able to be stopped, most aspects of climate change are expected to persist for many centuries (IPCC, 2013). The complexities, both of the system and of its impacts, are illustrated in Figure 1.

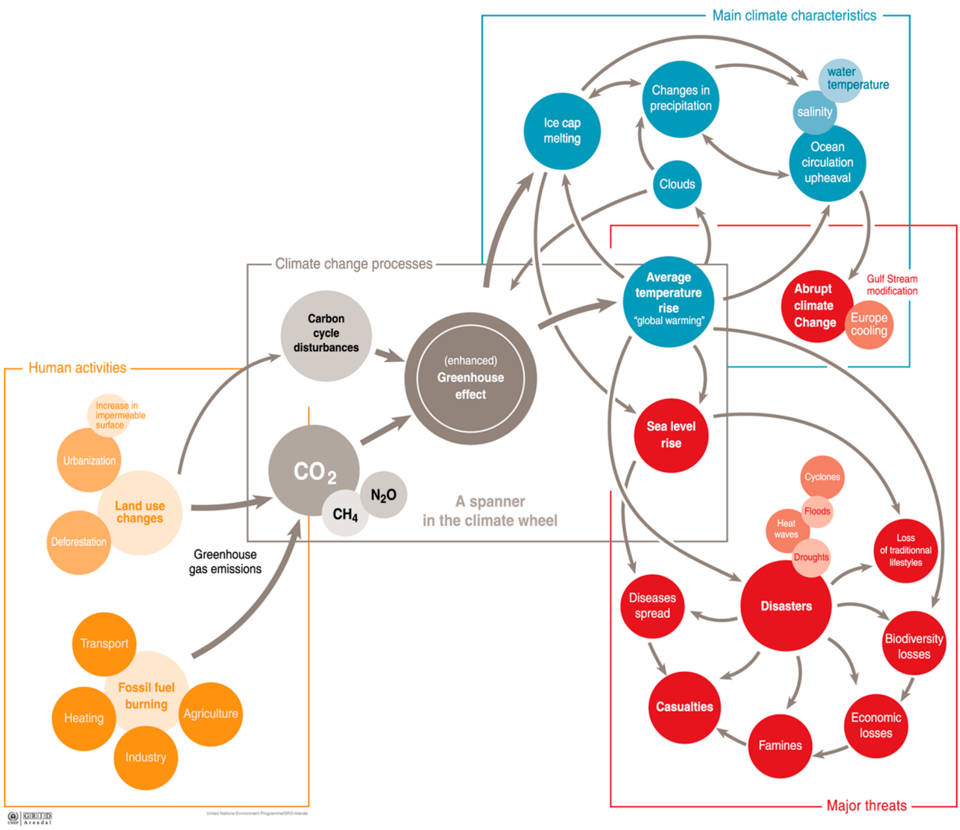


__Figure 1:__ Climate change: processes, characteristics and threats. UNEP/GRID-Arendal (2005).

News from Australia	Evidence of flood devastations
Date: January 2011 **Australia flooding could continue for week.** Water up to 16 metres deep has flooded towns and roads. Sydney-based freelance reporter Peter Hadfield said. The rain eased Thursday, but river levels continued to rise in many locations and the Queensland disaster management agency said some areas are still bracing for more flooding. The crisis has been triggered by Australia's wettest spring on record. At least six river systems across Queensland have broken their banks. The floods have affected about 200,000 people, and many have been evacuated from their homes. ***Source:*** *CBC news, January 2011*	 Aerial view of Queensland flooding, Australia (Photo: CBC news).
	 Displaced neighbourhood by Queensland flooding, Australia (Photo: CBC news).

Figure 2: *Flooding in Queensland, Australia.*

News from East Africa	Evidence: Photos of drought devastation
Date: November 2011 **An epic drought has been cast upon countries like Kenya, Ethiopia, Somalia and Uganda**. The severe drought, that now occurs year on year, has led to severe shortages of water, food and livestock. It is estimated that 23 million people are threatened by the crisis. The most severely affected area encompasses the semi-arid regions of eastern and northern Kenya, Western Somalia and some southern border areas of Ethiopia. The drought developed in parts of east Africa in late 2010 and continued through most of 2011. Over eastern and northern Kenya; it was the driest 12-month period on record at some locations within the region. ***Source:****The Watchers, November, 2011*	 Severe drought killed live stock in Kenya (Photo: Global-Changes).

Figure 3: *Drought in East African countries.*

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events. Trends in climate extremes and impacts consist of a decrease in the number of cold days and nights, an increase in the number of warm days and nights, an increase in heavy precipitation events, an increase in tropical cyclone activity, a shift in extra-tropical storm tracks, more intense and longer droughts, and an increase in extreme coastal high water related to increases in mean sea level. These trends, while firmly in place, have strong regional variations (IPCC, 2012). Figures 2 and 3 illustrate such problems.

In order to cope with climate change, strategies for adaptation and mitigation are developed. Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change. Mitigation refers to reducing Green House Gas (GHG) emissions and enhancing GHG sinks and GHG reservoirs (UNFCCC, 2013).

The ability to quantify the extent of past changes and then to extrapolate to likely future change depends heavily not only upon the collection of reliable data, much of which is spatial in nature, but also upon the integration of that data with other data sets. Robust analyses and analysis tools are essential to the process. Reliable future projections depend heavily upon the length and quality of the data sets used as well as upon human understanding of a climate system that is exceedingly complex in its interactions.

2.1 Global, Regional and Local Perspectives

In March 2009, the UN secretary general Ban Ki-Moon stated that, "*climate change is the defining challenge of our time*" (Urban World, Issue 5). In his view, the combined impacts of climate change with the recent global financial crisis puts at risk all the efforts made by the global community to meet the Millennium Development Goals of alleviating poverty, hunger and ill health. Unfortunately, those who suffer the most from climate change are the poor, i.e., those who contributed the least to this planetary problem are disproportionately at risk. On the other hand the global challenge of climate change also provides a range of opportunities. The former Executive Director of UN-Habitat, Dr. Anna Tibaijuka, believes that prevention of climate change impacts can be greatly enhanced through better land use planning and building codes (thus enabling cities to keep their ecological footprint to the minimum), and also by ensuring that their residents, especially the poorest, are protected as best as possible against disaster (Urban World, Issue 5).

Vulnerable countries such as Bangladesh and most small island states often claim to be the victim of climate change "crimes" caused by the richer part of the world. This issue of global responsibility is in the heart of the global climate change agenda. Bangladesh, for example, is one of the world´s poorest nations and also the country most vulnerable to sea-level rise. A sea-level rise of 1.5 meters would affect about 22,000 km^2 and 17 million people, i.e., 15% of the total population. A further example is the Himalayan countries of Nepal and Bhutan, sandwiched between the two emerging economies of India and China. In absolute terms, these two emerging economies have high rates of CO_2 emissions that, in turn, leave Nepal and Bhutan at the receiving end of the subsequent impacts.

Loss of healthy life years as a result of global environmental change is predicted to be 500 times greater in poor African populations than in European populations. This global inequity is well presented in Figure 4.

Issues of this nature point strongly to the need to develop climate change mitigation policies as partnerships across the global community. Irrespective of the success of such global negotiations, it is clear that adaptation to the regional and local effects of climate change will be required. While this may be facilitated by the building of spatially enabled land administration systems (thus enabling better impact analyses), key policy issues such as where to place new settlements and how to obtain clean water supplies will also have to be addressed.

At the local level there will be a need to identify, assess and manage vulnerable communities in relation to the complicated interaction between climate change, ecosystem degradation and increased disaster risk. IPCC (2007) predicts that, "*the resilience of many ecosystems is likely to be exceeded by 2100 by an unprecedented combination of change in climate, associated disturbances (e.g., flooding, drought, wildfire, insects, ocean acidification), and other global change drivers (e.g., land-use change, pollution, over-exploitation of resources)*". Such ecosystem degradation in turn triggers more disasters. Healthy ecosystems, on the other hand, act as a buffer, protecting communities from disasters and improving their ability to cope with climate change impacts.

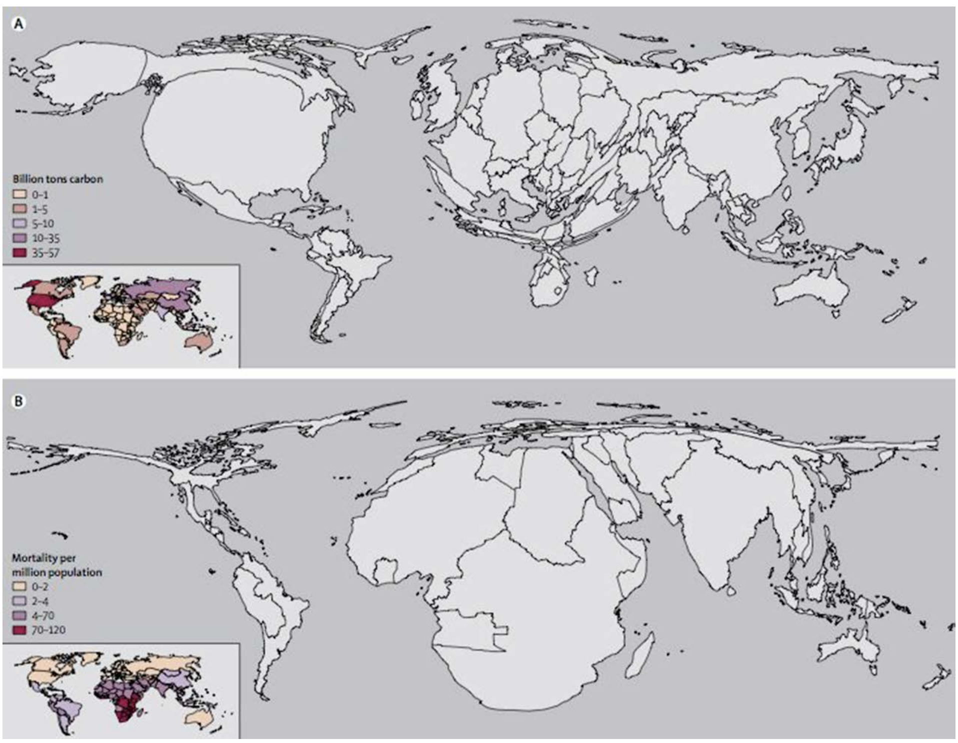


Figure 4: *The world in terms of carbon emissions of each country (top) and increased mortality as the result of climate change (bottom). Source: www.resilience.org/stories/2009-05-19/your-world-maps-climate-change-edition.*

It is thus clear that in dealing with climate change, international efforts must integrate with local, national, and regional activities.

2.2 The Need for Earth System Monitoring

An understanding of the complex interactions within the Earth system (whether a function of anthropogenic climate change or not), cannot be achieved without the collection of large volumes of data spread over long periods of time. The data, which must characterise Earth system processes, must be global, comprehensive, detailed, reliable and consistent. Such data are collected both by Earth fixed and space borne instrumentation. The longer the time series of such data the better the analyses performed on the data, and the more reliable the conclusions able to be reached.

The first steps towards a strategy for the integration of global Earth observing systems occurred in mid-1990 in the context of the UN Framework Convention on Climate Change (UNFCCC, 1998). It was recognised that if decision makers were to be able to best address global scale issues such as climate change and sustainable development, it would require the collection and integration of data from multiple sources and multiple platforms. This initiative further advanced in 1998 with the development of an over-arching strategy for conducting observations relating to climate and atmosphere, oceans and coasts, and land surface and the Earth's interior. As a result of the World Summit on Sustainable Development held in 2002, an unprecedented effort was initiated towards the coordination and integration of global Earth observations (Sahagian et al., 2009). Subsequent meetings established nine primary societal benefits that would flow from an integrated approach to earth observation. These are listed in Table 1 below.

The assessment of climate change and evidence for it can be found in nearly all these areas. For example, evidences can be seen in the frequency and intensity of storms, in ice cap melt, sea level rise, migrating species, habitat change and changing agricultural patterns. The separation of natural change from anthropogenic forcing relies on reliable data sets that have a long time series of data associated with them.

Area	Objective
Disaster	Reducing loss of life and property from natural and human-made disasters
Health	Understanding environmental factors affecting human health and well-being
Energy resources	Improving management of energy resources
Climate	Understanding, assessing, predicting, mitigating and adapting to climate variability and change
Water	Improving water resource management through better understanding of the water cycle
Weather	Improving weather information, forecasting and warning
Ecosystems	Improving the management and protection of terrestrial, coastal and marine ecosystems
Agriculture	Supporting sustainable agriculture and combating desertification
Biodiversity	Understanding, monitoring and conserving biodiversity

Table 1: *Nine Societal Benefit Areas of Earth Observations (from Sahagian et al., 2009).*

Reliable spatially referenced data sets, in turn, require stable, consistent reference systems – reference systems which themselves rely upon observations of the Earth's variable shape, gravity field and rotation. Such reference systems allow the definition of time dependent coordinates to points and objects both in space and on the Earth's surface. They are thus an indispensable foundation for all sustainable Earth observations (Plag et al. (2009). It is these coordinates that provide the spatial location of the data subsequently analysed to assess important elements of climate change processes.

2.3 The Need for Data Integration and Analysis

The Oxford Dictionary defines integration as: a) the act of combining (parts) into an integral whole; and, b) to complete by adding parts. In the case of spatial data, integration involves combining several geospatial datasets representing natural or artificial phenomena or information, normally of homogenous nature, into a complete heterogeneous one and then using this new data set for analysis or information retrieval purposes. When applied to the spatial analyses required for climate change studies, it may enable object-based image analysis, multi-scale and multi-dimensional phenomena analysis, impact visualization, and the assessment of glacier and ecosystem dynamics. A GIS-based framework can help us understand Earth's systems at a global scale, leading to better decision-making (ESRI, 2010).

At a more technical level Uitermark et al. (2005) have described spatial data integration as the process that is used to establish relationships amongst corresponding object instances in different, autonomously produced spatial datasets of the same geographic space. Integration can be carried out, for example, to enhance, improve or augment the overall quality and reliability of a dataset, or to enable spatial analysis for a specific user-required task. It is very difficult, for example, to assess the full impact of sea level change on coastal communities unless a sea level rise scenario is superimposed upon data sets showing both coastal topography and local urban settlement patterns.

By integrating different spatial datasets into the framework of (say) a National Spatial Data Infrastructure (NSDI), the full multifunctional nature of a spatial system, essential for assessing sustainable development and climate change scenarios, can be achieved. A NSDI, or an equivalent, thus plays an important role in combining information on a national scale, so helping to ensure both effective resource use and the development of comprehensive knowledge.

It is well recognized that the greater the number of comprehensive digital geospatial data sets available, the greater the number of integrative analyses able to be undertaken and the greater the potential value of the outputs – provided, of course, that the data sets are reliable and are based upon a common coordinate system. Thus the more comprehensive the integration of data, the more comprehensive the climate change impact analyses able to be undertaken, and the better the ultimate policy decisions able to result from those analyses.

2.4 Tools for Spatial Data Collection and Analysis

2.4.1 Data Collection Tools

The core data sets associated with climate change studies, i.e., those with a long time series of data, are associated with *in situ* measurements and measurement systems. These include trigonometric data, tide gauge data, meteorological data, ocean temperature data, gravity data and ice core data.

Historically, it has been the surveyor's task to construct and maintain the coordinate and height systems that have allowed nations to be mapped. These traditional two-dimensional, but now three and even four-dimensional coordinate based reference systems, have allowed spatial data of all types to be integrated into regional and national data bases. The ability to define uniquely a parcel of land, for example, and then to administer that land efficiently, has been a function of being able to correctly and uniquely reference its location. This in turn has been a function of each parcel being positioned with respect to some underlying reference system. Understanding the importance of these reference systems is foundational to some of the climate change mitigation and adaptation strategies discussed later in this report.

Surveyors have also been involved in safety of navigation and monitoring maritime and coastal environments. Apart from the measurement of tides, hydrographic surveyors monitor other ocean-related environmental phenomena such as ocean temperature, salinity, and currents. Hydrographic data input tools include singlebeam, multibeam and sidescan sonar, tide gauges, sound velocity profilers among others. Inputs from these tools are invaluable for ensuring safe navigation; supporting coastal zone policies; supporting economies through the transportation of goods; supporting national sovereign entities under the United Nations Convention on Law of the Sea (UNCLOS) through the provision of nautical charts; and, increasingly, for assessing and mitigating some of the effects of climate change, such as sea level rise and storm surge. Most importantly, changes in coastlines due to sea level rise may affect national claims under UNCLOS (Sutherland and Nichols 2006; UN 1997; Woodroffe et al., 2010; Sutherland et al., 2014).

Another traditional, but vital activity of surveyors has been the collection of both tide gauge data and the high precision levelling required when such tide gauges have been connected to local (hopefully stable) bench marks. These tide gauge data have formed the basis of the Mean Sea Level (MSL) height datums used both for the design of local infrastructure, and for national mapping. It has been the surveyor's task to design and monitor these networks over long periods of time (e.g., Hannah, 1990).

In order to support the above traditional functions, the surveyor traditionally used aerial photography, theodolites, levels, depth sounders, and various types of distance measurement equipment.

However, over the last four decades, new, high precision Earth based measurement systems have developed. Satellite laser ranging (SLR), lunar laser ranging (LLR) and very long baseline interferometry (VLBI), have not only vastly improved the accuracy of national spatial reference systems but have allowed high precision global reference systems to be developed. In the last two and a half decades these have been complemented by a global navigation satellite system (currently based around the GPS system) and by the Doppler Orbitography and Radio-positioning Integrated Satellite (DORIS) station network. Many of these different measurement systems are co-located and now operate at an internal network consistency of one part per billion (Rothacher et al., 2009). When further combined with a global network of superconducting gravimeters and geodetic timing stations, they provide the global spatial reference framework outlined in Sec.2.1 (Rothacher et al., 2009). Some of these high precision systems (e.g., GPS) act as inputs into new maritime data collection tools such as multibeam and side scan sonar systems.

Contemporaneously with the development of Earth based measurement systems has been the development of space borne sensor systems. Such systems, which are now vital to global change studies, are able to observe a wide variety of earth processes globally, uniformly and with rapid repetition rates (Plag et al., 2009).

For example, Gravity satellite missions such as CHAMP (launched in July 2000), GRACE (launched in March 2002), and the just completed GOCE mission are able to detect both seasonal variations and trends in the Earth's gravity field. These in turn provide unique information about mass transport, such as the water cycle in large river basins, changes in aquifers, and the melting of ice sheets in Antarctica and Greenland (Rothacher et al., 2009). These data are critical to the determination of the cause of sea level rise. The GOCE mission produced gravity data that when combined with satellite altimetry data enable the direction and speed of geostrophic ocean currents to be tracked.

Over a period of about three decades or more, radar altimetry has been found to be a very reliable and efficient method of monitoring ocean currents and changes in global sea levels. The TOPEX/Poseidon mission, launched in August 1992, provided the first high quality global ocean data set capable of being used for the assessment of eustatic sea level rise. This mission has subsequently been followed by JASON-1, JASON-2 and ENVISAT missions. An additional mission (CyroSat-2), uses a radar altimeter in a Synthetic Aperture Radar (SAR) mode, to determine both ice sheet and sea ice elevations, thus directly monitoring changes in the ice covered parts of the globe.

Other satellite missions such as Landsat and more recently, RADARSAT and IKONOS have produced a wealth of image data. The sensors on these spacecraft use reflected or backscattered sunlight as their radiation source. They collect and transmit data from different parts of the electromagnetic spectrum which, when combined with calibration (or ground truth) data, enable vast areas of the Earth's surface to be monitored for such things as changes in vegetation, land usage, plant diseases, etc. More recent developments have involved the use of light detection and ranging (LiDAR) instrumentation. When deployed on aircraft these instruments can produce very accurate heights for objects and features on the Earth's surface. Indeed, when flown at lower levels, the data makes it relatively easy, for example, to construct seasonal beach profiles thus allowing ongoing monitoring of the coastal margin. An even more recent step in this process has been the development of drone technology which allows high resolution digital cameras to be deployed in remote areas on a very cost effective basis.

Underlying all of these satellite, aircraft or drone based sensing systems is the need to be able to position these objects in three-dimensional space as they collect data. To this end the GPS system has been invaluable. While other GNSS systems are either in place or under development (e.g., GLONASS, Galileo), the GPS system has been operational for well over two decades. While conventionally thought of as being used for positioning purposes only (whether on a stationary or a moving platform), it has also been found to be useful for a variety of other purposes such as the study the terrestrial water cycle (Larsen and Small, 2013), and as a meteorological sensor (Rocken et al., 1997).

In summary, the data collection tools available to the surveyor have shown dramatic advances over the last two decades. They allow the monitoring of Earth cover and Earth features on a scale and accuracy never before imagined. The data sets so produced, when accurately geo-referenced and integrated, allow detailed analyses of global change on a continuous or semi-continuous basis.

2.4.2 Analytical Tools

There are many analytical tools available to the surveyor that can assist in determining the extent of climate change and its impacts. Some, such as least squares analysis and principal component analysis (e.g., Hannah, 1990; Hannah and Bell, 2012) can be used to quantify change. Other mathematical methods, some involving complex processing algorithms sit behind the techniques used to monitor land motion or land use change from satellite based measurement data.

Most importantly, however, are the GIS tools used to integrate data from multiple (re) sources thus allowing important, "what if" analyses to be made. It is here that the climate change impact analyses can be best addressed.

However, it is important to recognise that some fundamental challenges remain, particularly when it comes to simultaneously incorporating sets of geospatial data having different nature, form, and type. For example, geospatial data integration may involve vector or raster data, or a mixture of both. Raster datasets may include images, raster maps and Digital Terrain Models (DTMs) that may consist of different resolution, accuracy, level-of-detail, reference systems and point-in-time. Vector datasets will normally show differences in geometric scale and accuracy. While the integration of these datatypes can be achieved through a simple superimposition, the models that are incorporated into such processes are usually much more complex. They may entail the use of image-processing and image-recognition techniques, spatial data registration, matching, transformation, and more.

The most common data heterogeneities existing among different spatial datasets required for integration are: spatial reference systems (datums), data formats, schemes, and geometric scales and resolutions (Villa et al., 2007). Due to the complexity of these heterogeneities, the problem of developing a comprehensive and generic integration mechanism is often impossible. For this reason, various methods have been developed, each aiming to solve a specific problem derived from the specifications of spatial datasets used.

A general, three-stage, spatial data integration workflow exists (e.g., Feldmar and Ayache, 1994; Siriba et al., 2012). These stages are:

- *Pre-Integration*, which entails the choosing of a common schema for the geospatial datasets used.
- *Matching and Modelling*, which results in either a global, or even better, local reciprocal modelling framework for the different datasets.
- *Integration.*

In many cases a global working integration schema is replaced with a local one (as required with local or limited climate change analysis). This overcomes limits in the modelling and analysis processes, in turn enabling local trends and precise localized inter-relations to be quantified. It also enables noise and roughness of the solution to be filtered out (Dalyot and Doytsher, 2013). Rigorous local modelling results in hierarchical integration schemas that can sometimes resolve the consistency and reliability problems associated off-the-shelf GIS packages (Doytsher, 2013). For example, preserving height continuity while not addressing the planar irregularities and discrepancies that might exist among the different geospatial datasets, or, neglecting to address the problem of local spatial adjustments (Dalyot et al., 2008).

With respect to climate change adaptation and mitigation, analysis methods and tools are customized from various scientific disciplines, such as landscape and urban analysis, water and environmental management, crisis and conflict prevention models – all are aimed at ensuring a sustainable future while reducing disaster risk (e.g., Schipper and Pelling, 2006). Generally speaking, climate change models are based on a combination of physical data that iteratively improve their ability to simulate current and past climate changes, thus making it possible to predict future climate changes. It is crucial to utilize simultaneously diverse geospatial datasets in order to further the understanding of global – as well as local – changes. These can be satellite image observations, land use records, ecological information and topographic models and processes. The combination of such data can deliver a much improved understanding of climate change processes such as environmental indicators, quantitative climatic conditions, numerical model simulations – and more.

3 SPATIAL ASPECTS OF MITIGATING AND ADAPTING TO CLIMATE CHANGE

Surveyors have a wide range of skills and tools that can be used to help communities adapt to climate change and to mitigate the effects of climate change. The use of these skills and tools can be seen across a broad spectrum of human activity – many of which will be discussed in this section.

3.1 The Design of Urban Communities and Human Settlements

In the coming decades, it is expected that climate change will result in an increase in the intensity, frequency, duration and extent of weather related hazards in many parts of the world. While such events will be global in their distribution, their impact is likely to be most acute in urban areas and in the least economically developed countries (Fritz, 2010). Loss of life, population displacement and migration are likely to be the outcomes (Ehrhart et al., 2009).

IPCC (2007); Ehrhart et al, (2009); and Gemenne, (2011) suggest the following mitigation and adaptation measures.

- The development of new drainage systems (including overland flow routes) capable of handling much greater volumes of surface water in the urban environment.
- The development of risk management plans for vulnerable communities. For example, cities and towns with coastal or river boundaries should develop new flood protection policies including the avoidance of new construction on low-lying coastal or river plains, building new protective structures, and devising managed retreat measures.
- The implementation of planned migration strategies. This will require current barriers to migration being relaxed, particularly for vulnerable small island developing states.
- Supporting capacity building and climate change adaptation initiatives by local peoples.
- Developing timely and efficient disaster recovery and reconstruction strategies.

The descriptor 'resilient cities' (ICLEI, 2013) is used to describe the ability of cities to cope with stress, and to survive, adapt and bounce back after a crisis or disaster.

Additional to the above, it is important to realise that cities and urban areas are not only the home to approximately 70% of the world's population, but they consume the majority of global resources and are responsible for most of the greenhouse gas emissions. Between 1970 and 1990 direct emissions from agriculture grew by 27% and then stabilised. Over the same time direct emissions from buildings grew by 26% but indirect emissions by 49%, due to their high levels of electricity use. Buildings count for 30–40% of the total energy consumption in western countries of which 50% is related to indoor heating and cooling (IPCC, 2007).

In the developed world, cities offer many opportunities for climate change mitigation. For example, improved building designs can lead to better energy efficiency, less pollution and greater resilience. To achieve 'low carbon cities', 'post carbon cities', 'transition towns', or 'smart cities', greenhouse gas abatement, energy conservation strategies and land use planning should be connected.

In general, two kinds of measures are proposed. First cities should be more compact. This relates to the control of urban sprawl, densification processes, regeneration of rundown urban areas, consolidation of already urbanized zones, infill of vacant lands, extension of existing buildings, reduction of travel demands, and more efficient public transport. These are all urban design issues.

Secondly, urban spaces should be better designed. This is related to mixed use areas, green spaces, better orientation of buildings, improved solar gains, sunlight availability, site layout, proximity of residences to facilities and services, access to workplaces, land use diversity and urban quality. Although energy saving and emission control measures are often applied to single buildings, plants, and technological systems, energy consumption and greenhouse gas reduction are particularly connected to the urban form and density, to activities allocation and to transport. They thus involve spatial and land use planning decisions (Zanon and Verones, 2013).

Apart from these two measures, adaptation to the impacts of climate change can be achieved via effective urban management. For example, planning and land use controls can prevent people from building in zones at risk of flooding and landslides. Guidelines and regulations can increase resilience. Governments can not only design infrastructure that has high levels of climate proofing, but also mobilize stakeholders to contribute their technical and even financial resources towards joint endeavours – moves that make sound economic sense (UN Habitat, 2002).

In the developing world a different suite of issues are to be found. Rapid urban expansion, for example, which is occurring in many developing countries, largely involves agricultural land being taken over for informal or formal urban development. Tenure insecurity may cause illegal sales of land or losses with limited or no compensation. Loss of land without compensation also means loss of livelihood. There are features of informal settlements that make them more susceptible to climate change related risks. These include insecure land tenure, limited or no access to basic infrastructure and services, and overcrowding (World Bank, 2011).

Cities in the least economically developed countries and in Small Island Developing States (SIDS) are among those that face the most difficult challenges. They often have limited capacity to adapt and need the assistance of the international community to help protect the lives and livelihoods of their people, while still attaining their development goals (UN-HABITAT, 2010). Many of these same countries are also among the more vulnerable to climate change and natural disasters.

Special attention needs to be drawn to the urban dwellers in low income nations. Vast numbers of urban dwellers have no all-weather roads, no piped water supplies, no drains and no electricity supply. They live in poor quality homes on illegally occupied or subdivided land. This, in turn, inhibits any investment in more resilient buildings or the provision of better infrastructure and services. A high proportion of such urban dwellers are tenants with limited capacity to pay for housing. In addition, the landlords have no incentive to invest in better quality buildings. In this type of environment, urban planning needs to focus on providing low income groups with safer legal alternatives (e.g., Figure 5). Where possible, land use management should protect and enhance the

Figure 5: *Examples of disaster prone settlements due to poor land use planning.*

natural buffers that provide a defence for cities and their surrounds (Satterthwaite et al., 2007).

In dealing with such issues as have been raised above, it is clear that climate change adaptation needs to be systematically incorporated into urban planning practice (Wamsler et al., 2013). The quest for such climate proof urban management presents a challenge to multidisciplinary teams of professionals who have to grapple with such issues. Amongst these professionals it is the land surveyor who, with his knowledge of land law, cadastral systems, urban design and spatial information systems, can often provide the glue that links the other specialists together.

3.2 *The Administration and Use of Rural Areas*

Land is a fundamental resource that allows people with access rights an opportunity for shelter, food production and livelihoods. The 1948 Universal Declaration of Human Rights recognizes the right to food as part of the right to an adequate standard of living. FAO (2012) recommends that States protect the tenure rights of small-scale producers who provide a major share of agricultural investments which, in turn, contribute significantly to national food security.

Land use is an important factor in climate change studies. The vegetation on the Earth's surface, for example, holds three times as much carbon as the atmosphere. More than 30% of all greenhouse gas emissions arise from the land use sector.

Deforestation, agriculture and livestock grazing are the major land use changes that increase the release of carbon into the atmosphere (31% of human-induced GHG emissions, i.e., 15 billion tons of CO_2 equivalents). The burning of fossil fuels and land use changes are the two dominant sources. Fossil fuel burning contributes 27.7 billion tons of CO_2 equivalents and land use changes 15 billion tons (non-forest agricultural land use change generates 6.5 billion tons and deforestation for agriculture 8.5 billion tons). It has been estimated that agriculture will have a sequestration potential of 4.0–4.3 billion tons of CO_2 equivalents by 2030 (Scherr and Sthapitt, 2009).

Carbon sinks are not only in the oceans and the earth's crust, but also in tree biomass, vegetation, roots, forest litter, dead wood, and soil. Unless the carbon is locked in forest biomass over the long term, it will contribute to the growing greenhouse gases in the atmosphere with long-term climate consequences (Barnes and Quail, 2009).

Land use has special importance in helping to mitigate climate change, for while other sectors aim to achieve a lower level of greenhouse gas emission, land use changes can also remove greenhouse gases from the atmosphere through sequestration and storage. Indeed, agricultural production can play a vital role in adapting to and mitigating the impact of climate change in that it is, firstly, an important emitter of greenhouse gases, secondly, has the highest potential for reducing emissions and, finally, is the sector that is most affected by climate change (Quan and Dyer, 2008).

3.2.1 The Impact of Climate Change on Rural Areas

The World Bank identifies five main factors through which climate change will affect the productivity of agricultural crops: changes in precipitation, temperature, carbon dioxide fertilization, climate variability and surface water runoff. Increased climate variability and droughts will affect livestock production as well. Crop production is directly influenced by precipitation and temperature. Precipitation co-determines the availability of freshwater and the level of soil moisture, which are critical inputs for crop growth. Higher precipitation or irrigation will reduce the yield gap between rain-fed and irrigated agriculture, but it may also have a negative impact if extreme precipitation causes flooding (World Bank 2007).

In terms of the Global Food Security Index Africa and Asia face some of the greatest challenges. Special attention should be given to Sub Saharan Africa because agriculture is of great importance to most Sub-Saharan African economies, supporting between 70 and 80% of employment and contributing an average of 30% of GDP and at least 40% of exports (Commission for Africa, 2005). However, specific agro-ecological features, small farm sizes, poor access to services and knowledge, and low investment in infrastructure and irrigation schemes have limited agricultural development in Sub Saharan Africa. Given the likelihood of greater climate variability in the future, the development of irrigation plus improvements in agricultural productivity are key variables, not only for future economic development, poverty reduction, and food security, but also for climate change adaptation (Calzadilla et al., 2013).

Agriculture is by far the biggest global user of freshwater resources and is consequently highly vulnerable to climate change. In most developing countries, the agricultural sector provides the main livelihood and employment for most of the population and contributes considerably to national GDP. Therefore, reductions in agricultural production caused by future climate change could seriously weaken the food security and worsen the livelihood conditions of the rural poor (Commission for Africa, 2005).

3.2.2 Possible Adaptation and Mitigation Strategies

Scherr and Sthapitt, (2009), suggest the following strategies.

- Enriching soil carbon. Soil is the third largest carbon pool on the Earths' surface. Agricultural soils can be managed to reduce emissions by minimizing tillage, reducing use of nitrogen fertilizers, and preventing erosion. Soils can store the carbon captured by plants from the atmosphere by building up soil organic matter – a process that also has benefits for crop production.

- Farming with perennials. Perennial crops, palms and trees constantly maintain and develop their root and woody biomass and associated carbon, while providing vegetative cover for soils. There is significant potential to substitute annual tilled crops with perennials, particularly for animal feed and vegetable oils, as well as to incorporate woody perennials into annual cropping systems in agroforestry systems.

- Climate-friendly livestock production. Rapid growth in demand for livestock products has triggered a huge rise in the number of animals, the concentration of wastes in feedlots, and the clearing of natural grasslands and forests for grazing. Livestock related emissions of carbon and methane now count for 14.5% of total GHG emissions – more than the transport sector. A reduction in livestock numbers can help, including rotational grazing systems manure management, methane capture for biogas production, and improved feeds.

- Protecting natural habitats. Four billion hectares of forest and five billion hectares of natural grasslands form a massive carbon sink – both in vegetation above ground and in root systems below ground. Farmers should be encouraged to maintain natural vegetation through product certification, payments for climate services, securing tenure rights, and community fire control.

- Restoring degraded watersheds and range lands. Degradation has not only generated a huge amount of GHG emissions, but local people have lost a valued livelihood asset as well as essential watershed functions.

To achieve these goals, either incentives will need to be provided or governments will have to mandate improved rural land management practices. Institutional platforms exist in many countries to promote sustainable land management on a large scale. Community land use planning and action models are widely implemented and can be strengthened (Scherr and Sthapitt, 2009). The allocation of property rights, together with security of tenure (Yegbemey et al., 2013), can be linked to allowable land use so as to provide incentives for farmers to implement environmentally sustainable practices. This is especially important for informal tenures such as customary land, tenancy, and informal settlements where the challenges are great. It is here that the surveyor, as a land professional can have a particular impact. Not only can surveyors partition land into parcels that reflect the landscape, but they can also define boundaries in such a way that rights, consistent with sustainable environmental practice, be allocated to specific parcels. These parcels and these rights can then be integrated by the surveyor into spatially enabled land administration systems. This will allow governments to incrementally improve tenure security, control access to hazard-prone land, and control inappropriate use of land (Enemark, 2010[a]).

3.3 The Management of Peri-Urban Areas

Peri-urban areas are found at the interface between city and country where urban and rural uses of land mix, and often clash. It is an area of increasing policy focus. Ravetz et al. (2013), consider that this area, "*may be the dominant urban form and spatial planning challenge of the twenty-first century. In older industrial or post-industrial countries the peri-urban is a zone of social and economic change and spatial restructuring, while in newer industrializing countries, and most of the developing world, the peri-urban is often a zone of chaotic urbanization leading to sprawl.*" In developed countries these areas are generally managed intensively so as to prevent urban sprawl and protect agricultural land use. In developing countries they tend to be areas whose land-use changes rapidly as people and cities respond to urban expansion or migration pressures.

The International Organization for Migration (IOM) has noted not only that climate change and environment degradation are interrelated, but also that environmental degradation and disasters can causes of migration (IOM 2010, 2011[a], 2011[b]). Climate change thus has the potential to cause a movement of people from rural to urban centres resulting in significant effects on ecosystems. In reality, environmental factors have long had an impact on global migration flows, as people have historically left places with harsh or deteriorating climatic conditions. Such migration can have both positive and negative effects on the local coping capacity – both in the areas from which these migrants originate, as well as in their temporary or permanent destinations.

Newlands (2011), lists the following factors as likely to influence climate change migration:

- *Sea-level rise*, causing inundation of productive, low-lying agricultural coastal areas and river deltas.
- *Higher temperatures*, shifting optimal temperature zones for crop yields. Warmer temperatures may also increase vulnerability to pest infestation and disease.
- *Disruption of the hydrological cycle*, altering precipitation and/or high rainfall events.
- *Severe storms*.

All of these factors have the potential to result in rural-urban migration. Such migration requires broader development policies, emergency preparedness, early warning systems and, most importantly, pre-emergency rural-urban land-use planning.

IOM (2010, 2011[a], 2011[b]) provides the following policy guidance.

- Effective early warning systems, contingency planning, well-informed populations, ready shelter and humanitarian assistance are crucial for improved disaster preparedness and mitigating forced migration.
- In expectation that climate change will increase the incidence of sudden and slow-onset disasters, disaster risk reduction strategies with a strong emphasis on long-term sustainable solutions are vital in reducing forced migration and in stabilising populations in those areas affected by degradation or disaster.
- Environmental impacts need to be understood and controlled.
- While the granting of permission for temporary stay or temporary protection for those displaced across international borders by natural disasters is already practiced in an ad hoc fashion, a more systematic approach for environmental migrants needs to be explored.
- Urban planning needs to account for the likelihood of increased rural-to-urban migration, driven by the need to provide for, and integrate, migrants.
- Environmental migration must be considered when seeking to develop policies aimed at producing long-term solutions for those who have had their traditional livelihoods disrupted.

While many of the issues facing peri-urban areas are similar to those found in urban areas, it is the need for long-term policy and planning that is particularly crucial. To what extent will unplanned urban encroachment be allowed versus the development of planned urban areas? How will those with existing land rights be treated? What land-rights, if any, will accrue to new occupants of such areas? What infrastructure will be built and where will it be located? These are all issues that fall within the professional domain of the surveyor.

3.4 The Management of the Coastal Zone

The land-sea interface is one of the most complex areas to manage. It is estimated that 10% of the world's population live in low elevation coastal zone areas (i.e., less than 10 meters above mean sea level), with over 50% of these living in urban areas. For many, retreat in the face of sea level rise and in an increase in the frequency and severity of natural disasters is not possible due to high population densities, shortage of land, and lack of alternatives. In this regard, Small Island Developing States (SIDS) are particularly vulnerable.

In general, the likelihood of increased displacement of urban residents from coastal areas will result in a need for enhanced systems for land delivery and improved systems for land use planning in both urban and rural areas so as to facilitate both planned and spontaneous people migration, both temporary and permanent (Quan and Dyer, 2008, Correa, 2011). However, resettlement decisions are complex and can have many implications. Conflict can occur if there is not agreement by the hosting legal proprietor, inadequate provision of infrastructure, or if resettlement occurs in areas of hazard risk. For resettled peoples, and host communities, security of tenure is essential (Correa, 2011).

The main land policy implication in coastal areas is intensified resettlement planning and a stronger role for the state in land use planning on areas at risk. This requires investments in land inventory plus land occupation surveys in both potential resettlement areas and areas of risk. This, in turn, requires the development of useful land information systems. Public land acquisition may be needed both to impede occupation in at risk areas and for resettlement, but this is also likely to require schemes for land sharing or release from private ownership (Quan and Dyer, 2008).

In addition, some rethinking of traditional land-tenure practices will be needed. In the South Pacific, for example, some 83–97% of land remains vested in the stewardship of indigenous guardians who retain the superior interest in and control of the land (FIG, 2010[b]). Where freehold title to land has been granted in the past, or where such superior interests exist, it may be time to move to a leasehold model. Freehold implies permanency, whereas leasehold implies the opposite. Preparing for future inundation, particularly in the coastal margins, may be better served if land-holders had a more temporary (or time-limited) view of their holdings or land tenure rights (Hannah, 2013).

3.5 The Use of Forest Resources

The largest source of carbon emissions has been from fossil fuels, followed by land use change – the latter stemming predominantly from the conversion of forests to agriculture. Drivers of land use change include agricultural expansion, urbanization, population increase, affluence, and technical change. Deforestation, or the conversion of forests to agricultural land, accounts for the loss of 13 million hectares each year. Latin America and Africa have suffered the largest net loss of forests, estimated at 4.3 and 4.0 million hectares respectively from 2000 to 2005 (FAO, 2005).

The UN programme to reduce greenhouse gas emissions from deforestation and forest degradation (REDD and REDD+) aims at planting 40,000 km^2 of forests to partly compensate for the 130,000 km^2 that is cleared annually (comprising 20% of the world's greenhouse gas emissions). A tree planting programme produces voluntary emission reduction units (VER's).

In Article 3.1 of the Kyoto Protocol, parties agreed to limit and reduce their greenhouse gas emissions between 2008 and 2012. This deadline has now been extended to 2020. Furthermore, countries that signed the Protocol can use afforestation, reforestation and deforestation as potential contributors to the reduction of emissions (Article 3.3). REDD has identified above ground carbon storage in forests as the most feasible carbon pool to conserve (Barnes and Quail, 2011).

Unspecified property rights over forest areas, combined with insecure tenure and the allocation of forest land to commercial users by governments have led both to widespread deforestation as a result of uncontrolled logging, and to the conversion of forest land to other uses (Quan and Dyer, 2008). In such cases the incentives to improve productivity and conserve forests are undermined. For this reason ownership rights over land, over the carbon sequestered, and the management control of REDD projects are the most critical elements to be accounted for in REDD projects (Quan and Dyer, 2008). One option is to link systematic or sporadic land titling programs to REDD projects. However, land professionals are increasingly using a "fit-for-purpose" approach aimed at all tenures along a continuum of land rights. This approach emphasises the identification of low-cost and pro-poor land tools that can be used for all tenure types.

While approximately 22% of forests worldwide are reserved for personal use and/or owned by the community and indigenous groups, governments still control the large majority of the forested areas. A commitment to good forest management plans can help mitigate some of the negative impacts of poor stewardship (Barnes and Quail, 2009).

Tenure regularization for existing forest dwellers and collective titling for indigenous groups are essential measures to ensure that deforestation schemes respect their rights and reduce land use pressure and the need for resettlement to other areas. More secure property rights for forest dwellers together with better systems for valuing and pricing forest resources to include their environmental and carbon mitigation functions also have important roles to play in safeguarding forests as stores of carbon and in reducing carbon emissions (Quan and Dyer, 2008). Formal land administration systems can help through the demarcation of boundaries, cadastral and participatory mapping of social tenures, and with the recording of rights (Mitchell and Zevenbergen, 2011).

3.6 The Establishment of Carbon Credit Markets

Articles 3.3 and 3.4 of the Kyoto Protocol provide for the use of greenhouse sinks (carbon sequestration and storage in soils and vegetation) to be used by countries to fulfil their obligation to reduce greenhouse gases. Articles 6, 12 and 17 establish a market for trading of 'assigned emission units' (AAU's). This is known as the 'compliance market', being structured to facilitate the trade in emission rights. Article 17 allows countries that have 'assigned emission units' to spare to sell their surplus credits to countries that are over their targets. The Protocol also offers an opportunity to generate Certified Emission Reduction Units (CRE's) in cooperation with developing countries in carbon sequestration projects.

The largest emission trader is the European Union's ETS (Emission Trading System) which started in 2005 with its cap-and-trade system. Under a cap-and-trade system a limit or allowance is set on the amount of carbon a company can emit. If the allowance is exceeded, the company then buys an allowance or a credit elsewhere or faces heavy fines. The seller, in turn, is rewarded for having reduced emissions. Other formal market emission trading schemes, either operational or proposed, can be found in the United Kingdom and in New South Wales, Australia.

Trading carbon takes place at the Chicago Climate Exchange and also in Europe. Although the markets are currently severely depressed, the value in 2011 of the global market amounted to $US 176 Billion, representing an emission volume of 10 billion tons of CO_2 equivalents (World Bank, 2012).

Apart from the compliance market, a retail offset market has also emerged, with a focus on voluntary participation by parties not bound by specific caps or regulations. Greenhouse gas emissions can be offset by investing in projects that provide emission reductions elsewhere in the form of 'Voluntary Emission Reduction Unit's (VER's). Critically, the voluntary market is still unregulated in that it has no market standard (Harris, 2007). Although also suffering from the present financial malaise, the value of the voluntary market in 2012 amounted up to $US 523 million representing 101 million tons of CO_2 equivalents (Peters-Stanley and Yin, 2013).

The voluntary carbon credit market leads to opportunities for such measures as carbon farming so as to generate tradable carbon credits through, for example, the reduction of livestock density, removal of wild grazing animals such as goats and rabbits, conversion from cropping to grazing, conversion from conventional to no-till cropping, revegetation (trees, fodder shrubs) and forestry development (Harper et al., 2007).

Whether an emission right creates a property right is questionable. An emission right appears to be exclusive, have value, and can be traded. The UK courts, the International Accounting Standards Board, the US Congress, and the FAO appear to consider emission rights as property rights. The Australian Carbon Right 2003 legislation provides for a title for the carbon in a sink, separate from that of the land, thus providing a legal base for ownership and trading. On the other hand, the Kyoto Protocol insist that no 'rights' are created (UNFCCC, 2001), as does the USA's Clean Air Amendment 1990. In addition the Australian Securities and Investment Act 2001says that the Australian Carbon Credit Units (ACCU's) are financial products and not property rights. Although confusing, Wallace and Williamson (2006[a], 2006[b]) make the observation that if the marketing of carbon credits requires a 'title for a carbon sink', then we should consider those rights as separate from the property title for the land ('unbundling of property rights')

(Barnes and Quail, 2009) assume that when dealing with carbon credits five fundamental questions should be answered, namely, (1) what rights, (2) whose rights, (3) when were they acquired and what is the duration, (4) how were they acquired, and (5) what are the spatial dimensions (location, extent, boundary dimensions).

3.7 The Development of Large Scale Agriculture

The International Land Coalition estimates that about 80 million hectares of rural land is devoted to large scale agriculture, funded largely through investment consortia. If biofuel production expands there will be greater competition for access to land. This, in turn, will require sound land tenure policies and land-use planning otherwise the livelihood of farmers, pastoralists, fishermen and forest dwellers without formal land tenure rights, will be at risk (HLPE, 2011).

Importantly, Arezki et al. (2012) note that:

> *"Secure property rights, transparent processes to ensure ventures' legitimacy and a legal framework to enforce rights are generally considered a precondition for foreign direct investment".*

They recommend placing a priority on improving land governance through recognizing local property rights and educating the local population on their rights and how to exercise them.

Quan and Dyer, (2008) elaborate on the relationship between climate change and land tenure, suggesting that accelerating expansion of bio-ethanol and bio-diesel production might offer opportunities for small-scale farmers by revitalizing land use in rural areas thus increasing both yields and incomes. However, such actions depend on land tenure security. They recommend the establishment of land policy frameworks that give clearer definitions of concepts of idle, under-utilized, barren, unproductive, degraded, abandoned and marginal lands in order to avoid land allocation problems. Existing land tenure patterns need to be recognized and implemented within a broader circumstance of taxation, subsidies, markets and trade.

Irrespective of the tenure situation, high precision agriculture techniques that use a combination of GIS and GPS technology to assist in defining management zones and in the optimal spreading of seeds, biological control agents and fertilisers have been shown to significantly reduce input costs whilst increase crop yields (Oliver, 2013). Precision agriculture, which has become a cornerstone of sustainable agriculture, is enabled by the spatial measurement and analysis tools used by the surveying community.

3.8 The Development and Use of Water Resources

The importance of water to the life cycle processes that support all ecosystems is well understood. All human activities are reliant on the availability of clean and reliable fresh water. The growing pressure for access, and rights to use the world's freshwater supplies, highlight the need to have well defined water boundaries and usage agreements between countries, provinces and neighbouring landowners. The surveyor plays a critical role both in defining and mapping the legal boundaries (including international boundaries), and in defining the spatial extent of the covenants associated with water rights.

Le Clue, (2012) drawing upon material in UN (2008) and The World's Water (2012), makes the following points:

- Over 90 per cent of the world's population lives in countries that share water basins. Globally, there are some 263 trans-boundary lake and river basins covering nearly one half of the Earth's land surface and accounting for an estimated 60 per cent of global freshwater flow.
- In addition to the above, about two billion people worldwide depend upon groundwater, which includes approximately 300 trans-boundary aquifer systems.
- While the UN Economic Commission for Europe Water Convention defines a watercourse as including groundwater hydrologically connected with surface water, there has been general neglect in recognising the trans-boundary nature of many of the world's aquifers, and our dependency on them for water supplies.
- The importance of trans-boundary waters to individual states creates a vital interdependency on the shared resources. The necessity to define robust shared use agreements is becoming increasingly important as access to freshwater supplies diminishes globally due to skyrocketing demand, climate change, over and inefficient use of water resources, and pollution.
- Despite both the importance and the extent of shared water resources no international, legally binding treaties presently exist. Those treaties that do exist typically take the form of bilateral or multilateral agreements, usually to provide governance in relation to a particular river basin.

The World's Water (2012), states the following:

> *"Among the most significant consequences of climate change will be impacts on the hydrologic cycle. Such changes are already being experienced (IPCC, 2007). As the climate changes, among the hydrologic impacts will be changes in precipitation intensity and duration, loss of snowpack and an acceleration of snowmelt in mountainous areas, loss of glaciers due to accelerated melt, and a risk of both more floods and droughts. Many of these factors will increase both water demand and water scarcity, affecting human and ecosystem health."*

IPCC (2014) is more specific, making the following points.

1. Each degree of warming is projected to decrease renewable water resources by at least 20% for an additional 7% of the global populations.
2. Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions thus exacerbating competition for water among agriculture, ecosystems, settlements, industry, and energy production. Conversely, water resources are projected to increase at high latitudes.
3. While there is, as yet, no widespread observation of changes in flood magnitude and frequency due to anthropogenic climate change, flood hazards are projected to increase in parts of south, southeast, and northeast Asia, tropical Africa, and South America.
4. By the end of this century, climate change is likely to result in less rainfall and less soil moisture in presently dry regions of the earth.
5. Climate change is expected to have a negative impact on stream flow and water quality, posing risks to drinking water.

As the global community grapples with these issues, it will find that the surveyor plays a vital role in the adaptation process. The surveyor's role not only includes the spatial definition and mapping of water resources, but also the precise spatial positioning required for the construction of the large infrastructure projects such as dams, canals, and water pipelines, that will be needed to assist at risk communities.

3.9 The Construction of Physical Infrastructure

The world's infrastructure is in severe deficit. The World Economic Forum estimates that global spending on basic infrastructure – transport, power, water and communications – currently amounts to \$2.7 trillion/year when it ought to be \$3.7 trillion/year (The Economist, 2014). The problems reveal themselves in such areas as crowded highways, power cuts, poor telecommunications, and poor fresh water supplies. Other include: lack of sewer and sanitation as well as structures no longer able to cope with increasingly heavier loads. Added to this deficit are the potential impacts from climate change. IPCC (2014) identifies these as follows:

- The integrity and reliability on pipelines and electricity grids (many of which have been built decades ago), are likely to become increasingly compromised.
- There will be variable impacts, positive and negative on water supply (see previous section). However, there will clearly be a need for new water supply infrastructure for those areas moving into a deficit in either water supply or water quality.
- Projected increases in extreme weather events resulting, for example, in flooding, will have major economic costs, both in terms of impacts (capital destruction, disruption) and adaptation (construction, defensive investment).
- Transport infrastructure is likely to be affected, not only because of malfunction, but also because of destruction. This, in turn, will not only require higher design standards but also climate proofing.

From a more general adaptation viewpoint, natural global balances that have existed for decades are likely to undergo significant change, in some cases resulting in the resettlement of peoples with a commensurate need for the construction of new infrastructure.

Typically, the surveyor, while not the designer of such infrastructure is an essential element in its construction. Water supplies for irrigation purposes require precise heights and geopotential calculations that are the very much the domain of the surveyor. The construction of the engineering infrastructure used to meet human needs require precise spatial positioning – a function that is solely the domain of the surveyor. The spatial definition of the easements necessary to provide legal security for such infrastructure is again solely the domain of the surveyor.

3.10 The Use and Conservation of Energy

In terms of energy demand, a warming climate will reduce the demand for heating, but conversely, will increase the demand for cooling, dependent upon geographic, socioeconomic and technological conditions. Irrespective of a net increase or decrease, currently demand is substantially met by the use of fossil fuels. Carbon dioxide (CO_2), arising from the use these fuels contributes almost 60% of the anthropogenic greenhouse gases. Fossil fuel is used in sectors such as energy supply, industry, transport, residential and commercial buildings, (IPCC 2007, 2014).

Policy and action plans to reduce the emission of CO_2 and other GHGs are executed on different governance scales. With the Kyoto Protocol, emission targets were set on a global scale. These targets are not only adopted by many individual countries, but also on a continental scale. The European Union has started a comprehensive package of policy measures to reduce greenhouse gas emissions. Individual countries have started their own programs on a national, regional and local scale. The surveyor is potentially able to make contributions to these policies, especially when he/she is familiar with the challenges of policy and decision makers at each scale.

In order to reduce or even stabilize these emissions it is necessary to find ways to manage the use and generation of energy. Reducing the need for fossil fuel energy or increasing the use of renewable energy sources such as solar or wind, are seen as important factors in climate change mitigation.

EU and other initiatives to reduce CO_2 emissions include:

- Using an emissions trading system as a key tool for reducing greenhouse gas emissions from industry
- Raising the share of energy consumption produced by renewable energy sources, such as wind, solar and biomass
- Increasing the energy efficiency of buildings
- Reducing CO_2 emissions from traffic and transport
- Using carbon capture and storage (CCS) technologies to trap and store CO_2 emitted by power stations and other major industrial installations.

(Lysen, 1996) gives an example of a comprehensive, three-step, energy mitigation strategy (also known as Trias Energetica). These steps include:

1. An increase in energy efficiencies (e.g., through better insulation of buildings),
2. Using renewable energy sources, and
3. Clean use of fossil fuels.

The surveyor is able to make a substantive contribution to each of these mitigation strategies. Potentially, isolated houses with low energy efficiency can be determined by analysing databases with cadastral and building code data. Building orientation and design (essential elements in energy efficiency) can be improved – these being influenced by the shape and orientation of the underlying land allotments defined by surveyors. Heat leakage in buildings can be determined by using infrared aerial photography. In small scale generation, such as solar panels on rooftops, the surveyor can contribute by building 3d models of cities using LiDAR scanning technology. This gives the opportunity to define the orientation and surface of individual rooftops and shadow effects, showing the most favourable spots for solar panels on a map. Additionally, the surveyor can support re-allotment of agricultural parcels in order to structurally reduce transport distances.

In addition, spatial planning is an important factor in making large scale renewable energy possible. New infrastructure such as wind or solar farms will need to be constructed, a process that again requires the professional skills of the surveyor. The placement of wind turbines with heights easily reaching 150 meters requires a careful decision making process, especially in densely populated areas. A balance has to be found between optimal wind conditions and the least amount of hindrance for people living nearby, such as reduced view, shadowing and noise pollution. Surveyors can support this process by providing geo-information such as buildings causing wind shade, wind rights, property rights and owners potentially experiencing hindrance.

Some of these mitigation options, while very practical, introduce their own problems. For example, in some countries where groundwater is used as an energy source, the issue arises as to the ownership of that energy source. Should ownership or use rights be attached to land parcels? Who should accrue the benefits of using that source? How is the spatial extent of that source to be defined? Again, these are questions that the surveyor can help resolve.

The clean use of fossil fuels can be made possible by capturing CO_2 – a technique that is increasingly being applied to reduce GHG emissions. This normally requires suitable underground geological formations. The surveyor is able to support the policy maker by supplying geo-information such as property rights, topography or land use.

Energy and climate policies are increasingly based on a spatial or regional approach. By combining climate goals, energy supply and energy demand for a certain area it is possible to find new opportunities in reducing CO_2 emissions in a sustainable way. One such way is by analysing the heat surplus of industries and heat demand in buildings. Van den Dobbelsteen et al. (2011) introduce the method of Energy Potential Mapping to analyse energy sources and energy sinks on a national, regional and city scale. They show that areas can become more self-sufficient, and in some cases even energy-producing. The surveyor can contribute to this by assembling relevant information from different spatial datasets and make it available to the decision maker.

3.11 The Spread of Disease

One element of climate change, not widely associated with surveyors, is found in the spread of diseases that affect both human health and biodiversity. Malaria, for example, varies seasonally in highly endemic areas. Excessive monsoon rainfall and high humidity enhance mosquito breeding and survival (McMichael et al., 2003). In the United States, mosquitoes capable of carrying and transmitting diseases like Dengue Fever now live in at least 28 states. As temperatures increase, rainfall patterns change, and summers become longer, these insects remain active for longer seasons and in wider areas, thus increasing the risk of human infection. Similar trends can be seen on a global scale where increases in heat, precipitation, and humidity can allow tropical and subtropical insects to move to new regions where the associated infectious diseases begin to thrive (http://www.nrdc.org/health/climate/disease.asp).

The effects of climate change on plants, animals, and in other environments are now well established. In the Arctic, for example, where temperatures are rising rapidly, parasites are developing faster and are able to be transmitted longer over each summer. Warmer water temperatures in and around coral reef ecosystems have facilitated infections by pathogenic fungi and bacteria (http://www.infectioncontroltoday.com/news/2013/08/climate-change-impacting-the-spread-of-infectious-diseases.aspx). The potential consequences are serious, placing growing numbers of species at risk of extinction.

Again it is the surveyor who has the enabling technologies that assist with these problems. GPS systems are now widely used to monitor the spatial extent of the spread of diseases and GIS systems (together with statistical and meteorological models) used to predict their future geographical spread. This type of modelling has been used in Africa, for example, to estimate how future climate-induced changes in ground cover and surface water would affect mosquitos and tsetse flies and hence, malaria, and African sleeping sickness (McMichael et al., 2003).

4 SPATIAL ASPECTS OF CLIMATE CHANGE GOVERNANCE

4.1 The Requirement for Spatial Data

Digital data has many forms and characteristics. Spatial data (also known as *geospatial data* or *geographic information*) is data or information that has a geographic identifier associated with it. Such data is typically integrated into land information systems and used to assist governments in developing policies that assist in both adapting to and mitigating climate change. In order for this to happen effectively, however, land registers and cadastres need to extend their functionality beyond existing conventional uses (Van der Molen, 2009).

The development of realistic approaches to climate change governance, require policy makers to seek facts and evidence to support their policies. Facts and evidence are often translated into measureable indicators and used for problem definition, policy development and policy evaluation. Data gathered by field surveyors or collected from existing spatial databases such as land registers and cadastres can be an efficient starting point in developing policy indicators. However, there is often a substantial gap between the core data and the information needed by decision makers. The data thus has to be translated and integrated into information systems with the challenges and demands of policy makers in mind.

Vranken and Broekhof (2012) show that core data such as cadastral parcels, buildings and ownership rights, enriched with other available national and statistical databases can be designed into coherent and tailor-made information packages. These information packages can be used as measurable indicators in climate change policy and can easily be represented in visual form.

The concept of marine cadastres has also taken root among nations that manage complex rights in marine and coastal spaces. The management of these types of rights are directly impacted by climate change (Sutherland and Nichols, 2004; Ng'ang'a et al., 2004).

To support decision makers and policy makers, surveyors need to understand climate change at a policy maker's level, have the ability to translate this into core data requirements, and then possess the knowledge of national spatial and statistical databases from which such core data can be drawn.

4.2 Impact on Policy

Managing cities, lands, forests, water, and energy resources not only requires an active land policy, but instruments to implement such policy and land tools to facilitate government intervention.

Land policies should:

(1) Allow for diverse but secure forms of tenure. For residents of informal settlements tenure security can provide incentives to invest in adaptation and mitigation measures (such as upgrading the quality of construction of their homes), contribute to community infrastructure, and use their property as a productive asset (World Bank, 2011).

(2) Provide improved land and natural resource information, including improved inventories of land occupation in urban and rural areas. This information should include improved analysis and mapping of natural hazard risks for informal settlements as well as better inventories of land available for resettlement or temporary relocation.

(3) Strengthen land administration. This needs to include increasing the capacity for low cost land survey and registration, safeguards against corruption, and developing comprehensive land information systems where land administration responsibilities are devolved to more local levels (Quan and Dyer, 2008). Land administration should be consistent with the principles outlined in FAO (2012).

(4) Strengthen land use planning. Conventional master planning has not worked well in developing countries and thus new innovative approaches are necessary. Angel et al., (2011), for example, suggests a new, 'making room' approach.

Land laws that are enforced effectively provide a mechanism for implementing land policies and promoting sustainable land use. The laws need to be developed in association with effective explanations, particularly in developing countries where there are low levels of literacy and thus difficulties in the dissemination of information.

In addition to the above, the effects of climate change and variability are felt through changes in natural eco-systems. Increasingly these changes will impact vegetation types, animal and insect species, and water supplies. Productive land will come under greater pressure, both for crop and livestock use and for human settlement. As a result land issues and policies will become important considerations for adaptation planning – planning that will need to strengthen land tenure and management arrangements in at risk environments (Quan and Dyer, 2008).

Enemark (2012) notes that some key policy issues to be addressed in relation to climate change involve avoiding a concentration of the population in hazard-prone areas and improving the resilience of existing communities to cope with the impact of future climate change. In a practical sense, building codes can help to mitigate the damage from disasters such as floods and earthquakes. Other aspects involve protecting the more vulnerable (women, children, the elderly, the very poor, ethnic and religious minorities) from being dispossessed from their land. Government and customary groups may need to work together, with closer ties being developed between land agencies and those responsible for disaster risk management.

Part of the policy response may not require additional government expenditure, but rather be achieved by changing frameworks that influence individual, household, community, company, and corporate investment. This can be done through adjusting policy instruments such as building regulations, land use zones, land subdivision regulations, pollution control, waste management regulations tax incentives and subsidies (Quan and Dyer, 2008).

4.3 The Need for Multi-Level Collaboration

When it comes to devising appropriate policies and actions for mitigating or adapting to the effects of climate change, multi-skilled teams are essential. Adaptation and mitigation by their very nature challenge professionals in the fields of land use, land management, land reform, land tenure, land administration and land law to incorporate climate change issues into their land policies, policy instruments and facilitating tools. While it is clear that land administration systems in themselves cannot induce mitigation and adaptation to climate change, they can serve as an essential information base for the implementation of land management policies (van der Molen 2009, Enemark 2012).

This suggests that in addition to appropriate registration of land tenure and cadastral geometry, information is required about the environmental rating of buildings, energy use, current and potential land use related to carbon stock potential and greenhouse gas emissions, clearer definitions of various land types related to the application of various legal regimes (e.g., what exactly is 'idle' land), flood and storm prone areas, salinization rates and transport indicators. This information might not necessarily be recorded in the land administration system itself, but at least connected with it, so that a strong link with private and public rights to land exists.

In the case of 'unbundled' property rights through, for example, the separation of carbon credit titles, these land administration systems should be able to register such rights and to attach appropriate geometric attributes to them so as to make those rights accessible for trade in the carbon credit market.

Land administration systems need also to fulfil their most vital purpose, namely to provide tenure security to right holders, with a focus on the poor, the vulnerable and indigenous peoples. With appropriate design, such systems can hold additional meta-data such as soil types and the value and use of land – information that can assist governments when they wish to encourage changes in livestock, crop production, or conversion to other uses such as reforestation. When particular land uses are required, such as for water storage or as carbon sinks, land administration systems should be able to provide information about right holders to be compensated in the land acquisition process, in such a way that people's land rights are respected and the risk of eviction is avoided.

If land reform is being undertaken land administration systems will provide information about the existing land tenure pattern and provide an operational process to change from old to new situations. Additionally, if governments choose to apply taxation as a measure to achieve some of their change objectives, land administration systems can be extended readily to provide relevant information about taxable objects, taxable values and taxable persons. In all of these activities, however, it must be remembered that land reform is complex, will require interdisciplinary collaboration, and should be fit-for-purpose. It requires a deep understanding of each country's unique situation and involves all sectors of the community in the design.

In this regard, and over the last few years there has been considerable focus on land governance in the surveying community and the land sector. Two significant developments resulting from multi-level collaboration have been the *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security* (VGs) developed by UN FAO, and the *Land Governance Assessment Framework* (LGAF) developed under the supervision of the World Bank. Together they not only provide land professionals with a structured framework to assess responsible governance, but also guidance to States on how to improve their governance. Through implementation, the World Bank has found that the LGAF is a "feasible and meaningful way to provide a comprehensive diagnostic tool and framework for policy analysis at the country level and identification of areas for improvement" (Burns et al., 2010).

It is clear that States should ensure that the legitimate tenure rights to land, fisheries and forests of all individuals, communities or peoples likely to be affected (by climate change) with an emphasis on farmers, small scale food producers, and vulnerable and marginalized people, are respected and protected by law, policies, strategies and actions (FAO, 2012). The World Bank (2011) argues that one of the ways States can build resilience in vulnerable groups is to strengthen land administration and consider improving security of tenure and service provision in informal settlements. If this task is to be achieved it will require multi-skilled teams of professional persons.

5 THE APPLICATION OF THE PROFESSIONAL SKILLS OF THE SURVEYOR

The surveyor is a practical pragmatic professional person who is skilled in spatial measurement, able to represent, interpret and analyse spatial information, highly knowledgeable in the administration and governance of rights to the land and sea, and capable of planning for the development and use of land resources. It is this unique combination of skills that allows the surveyor to not only collect and analyse data vital to understanding the impacts of climate change, but also to grasp many of the complex human, political and physical interactions that arise in dealing with climate change issues. In many regards the work and expertise of the modern surveyor spans the divide between the pure sciences and the social sciences. Thus the surveyor can be as much at home with high precision GPS measurement technology as with land planning and issues of tenure security. This broad base of subject knowledge and professional experience typically make surveyors holistic problem solvers in the following thematic areas.

5.1 Land Administration Systems

The effects of climate change will result in changes to livelihoods, human settlements, land use patterns, and tenure systems. The manner in which decisions about access to, use of, and control over resources are implemented and enforced, as well as the way that competing interests in resources are managed, is as central to the success of climate change adaptation and mitigation, as it is to livelihoods of people. Few of these things are achievable without cadastral, land tenure and land administration systems that reflect fully property rights and give tenure security. The need to devise such systems with an associated full transparency cannot be overemphasized. Without these, livelihoods will continue to be threatened and unsustainable land management practices maintained (Arial et al., 2011).

Achieving climate-resilient development requires responsible land governance and approaches to land use planning that are inclusive, and transparent, so that all people have a say in the way land use change occurs. The following issues illustrate points of tension.

i) Climate change projects in developing countries potentially have significant negative impacts on land users. In particular, land users with socially legitimate but informal tenure that is not recorded using a statutory process are at risk of exploitation from the powerful elite. Land administration systems can assist in formally recognizing and recording both *de jure* and *de facto* rights to land and resources. REDD (Reducing Emissions from Deforestation and forest Degradation), REDD+ and VCM (Voluntary Carbon Market) guidelines provide only limited requirements regarding how project beneficiaries are identified and how property rights are recorded. That gap can be bridged by land administration systems and by providing mechanisms for project boundary demarcation, cadastral and participatory mapping, mapping social tenure and overlapping rights, and certification (Mitchell and Zevenbergen, 2011).

ii) A carbon cadastre has been suggested as an alternative both for the identification of beneficiaries, and for providing management incentives for climate change mitigation activities (Barnes and Quail, 2011). An international carbon fund could then be connected to individual and communal landholders through 'carbon conservancies', in which only *de jure* and *de facto* land holders would collectively be eligible for membership.

iii) Unruh's (2008) research indicates that 'the possibility of sequestering large quantities of atmospheric carbon through woody biomass increment via tree planting projects in the tropics…has impressive potential'. However, afforestation and reforestation projects have to be initiated by governments that may have little power beyond those major urban centres where western notions of property rights and land law prevail. In remote and rural areas, customary land management may prevail. Unruh (2008) is strongly of the view that tree planting projects (i.e., land use change) require improved land governance, which in turn, assumes a single land law for the entire population through which the land rights of customary land holders can be guaranteed.

iv) The urban poor show significant capacity to take autonomous measures to improve their resilience so as to protect themselves and their properties from flood risks. This can be done through small scale investments such as building community flood shelters on higher ground, raising the level of buildings, digging local drainage channels, using more resistant building materials and locating wiring and more valuable household goods well above ground level. Such autonomous adaptations, however, remain constrained by insecure land tenure which creates disincentives for people to invest scarce resources in risk reduction (Quan and Dyer, 2008).

Climate change thus reinforces the urgency of scaling up the delivery of systems of secure land tenure. Given the high costs of land titling schemes involving full cadastral surveys of large numbers of small plots, and the often complex associated administrative procedures, low cost methods of land survey and registration need to be introduced, together with a diversity of land tenure arrangements and intermediate forms of land tenure which may fall short of full title. This is likely to involve the legal recognition of existing informal and customary land occupation, the provision of simple documentation, and the involvement of local community and customary leaders in the process Quan and Dyer, (2008).

The following, more complete picture of where and how new land administration systems can assist, is given in UN Habitat (2010):

- Consolidation of fragmented lands
- Sustainable management of rented land
- Overcoming unequal land distribution, land degradation, inefficient land use
- Tenure insecurity in relation to urban expansion
- Tenure security for slum dwellers
- Tenure security and investment capacity
- Tenure form in areas with customary tenure
- Social and environmental costs of elite capture of land reforms
- Devising better tools for land rights and registration, land use planning, land management and administration, land law enforcement, and land tax and valuation.

It is the surveyor who understands flexible and extendable land administration domain modelling, who has a variety of technical tools for producing secure low cost and rapid land inventories, who understands the relationship between humankind and land, and who has hands on experiences in crafting national and local land policies. It is the surveyors who are involved in crafting fit-for-purpose approaches that are aimed at all tenures along a continuum of land rights (Fig, 2014).

5.2 Spatial Monitoring and Measurement

Perhaps the most traditional and best known skill of the surveyor has been in positioning and measurement. Surveyors, for example, have been responsible for making the angle and distance measurements that have allowed nations to define unique two dimensional coordinate systems that in turn have been used for mapping, for referencing the positions of land boundaries, and for positioning dams, pipelines, power-lines and other vital infrastructure (e.g., Hannah and Maseyk, 1989). Surveyors have also been responsible for establishing national height networks, by making precise levelling measurements between stable benchmarks and linking these to one or more tide gauges through which mean sea level has been defined. In New Zealand, for example, it is the surveying profession (in conjunction with others) that has been at the forefront of the long-term sea level change analyses that have informed public policy makers on future climate change scenarios (e.g., Hannah and Bell, 2012).

While technology has changed, thus altering the tools of the profession, the surveyors' role in positioning and measurement has not. The surveyor now uses Global Navigation Satellite Systems (GNSSs) – usually GPS based, to make many of his or her spatial measurements. These measurements allow the spatial positions of structures and objects of all types to be monitored in real time or semi-real time. For example, it is a relatively simple matter to monitor the flexure of dams or bridges as they come under load from extreme climatic events. Vertical movements of tide gauges due to local sedimentary factors or tectonic forces have been precisely monitored by GPS techniques for at least a decade (e.g., Wöppelmann et al., 2009, Santamaría-Gómez et al., 2012). Such information is crucial to the determination of eustatic sea level rise.

As outlined in Sec 2.2, if global monitoring systems are to provide internally consistent and reliable data, then they will require stable global reference systems or, alternatively, an accurate knowledge of the movement of such systems with respect to time. For example, best estimates of global mean sea level (GMSL) change from satellite altimetry indicate a sea level rise from 1993–2013 of 3.2 ± 0.4 mm/yr compared to in-situ tide gauge data of 2.8 ± 0.8 mm/yr (Church and White, 2011; White, 2013). Stable global reference systems are an essential element in the assessment of this change. Again, this is the domain of the surveyor.

At a local level, the surveyor can use tools such as robotic total stations to lay out local infrastructure or to define land boundaries and/or the spatial extent of various land rights. GPS receivers, whether miniature or handheld can track the location of animals or the spatial spread of diseases. Laser scanners can be used in forests to detect biomass change or on open slopes to monitor or ice-pack change. It is these core measurement skills that help the surveyor contribute to climate change monitoring and adaptation.

5.3 Spatial Information Management

In most countries, surveyors not only collect and process spatial data for development, but they also act as the custodians and users of these data. As a consequence, surveyors have first-hand information and knowledge of vulnerable territories and environments that are threatened by the impacts of climate change.

The role of the land surveyor, in terms of spatial information management, can be viewed from three main perspectives – perspectives that are frequently intertwined with each other.

(1) **Data collection.** Here, some of the measurement technologies and instruments described earlier need to be seen as not just pure "measurement" tools, but also as the collectors of vast quantities of spatial data that it can be analysed and managed. This change is perspective has only occurred over the last two decades as new software and hardware systems, have been combined with cutting-edge geospatial processing algorithms. These have affected traditional methods for geospatial data–collection, processing and management (Doytsher, 2013). Technologies for the acquisition of spatial data have been extended to include digital photogrammetry, cartographic digitization and scanning, radar and sonar based imaging systems and LiDAR scanners. Since some of these technologies deliver data with very high levels of resolution, data-volumes have increased dramatically thus requiring new techniques for spatial information retrieval and production. This, in turn, is making it possible to analyse and understand climate changes with a much improved granularity both on local and global scales.

(2) **Data management.** Whereas the new geospatial tools and technologies described above set challenges, they also hold new potential. They allow the integration of social, economic, environmental, and geographic data (all elements and phenomena that are associated with climate change), into new knowledge-bases within timeframes that were not previously possible. For example, the generation of very detailed topographic and thematic mappings and information, which are derived from different data sources and at different scales, now allow data mining, interpretation, and visualization of different climate change scenarios (van Vuuren et al., 2011). This creates the opportunity to perform more effective forms of modelling, analysis and decision making, thus leading to more reliable and effective solutions. The new data acquisition technologies, as well as methods, algorithms and software packages, have allowed land surveyors (and the mapping community in general) to rapidly and frequently update, integrate and analyse geospatial data.

(3) **Data interpretation** while the collection and acquisition of geospatial data is now much more comprehensive and rapid, its assessment, interpretation and management require a high level of skill. The shift in focus of the surveyor from single point measurements and geodetic infrastructure to a more holistic, handling of spatial data infrastructure has enriched the land surveyor's professional scope when it comes to the facilitation of global scale observations and monitoring of processes, such as those associated with climate change (e.g., Higgins, 2009; Lebel et al., 2005; Sleeter et al., 2012). It is via the handling of geodata that land surveyors are increasingly able to enhance their contribution to the development of sustainable environments and societies.

In part, these new tools for data collection, management and interpretation have developed in response to new millennium challenges that relate both to our natural habitat and to changes in socioeconomic conditions – particularly in terms of settlement patterns, urbanization, urban growth, environmental degradation. Such challenges have also necessitated new and improved procedures for the governance and management of land, some of which fall outside the capabilities of traditional land administration systems (Enemark, 2009). Surveyors are at the forefront of developing new systems (e.g., Enemark, 2010[a]; Brody et al., 2010). They, along with other practitioners in the fields of land use, land management, land reform, land tenure and land administration are in the process of incorporating climate change issues into their land policies, land policy instrumentation, land information management, maintenance and administration.

These tools also allow the surveyor to undertake spatial modelling exercises such as are necessary for assessing the likely spread of diseases in the light of future climate change. GPS positional data can be integrated with terrain data and statistical and meteorological models to assist with these tasks.

In all of these activities the goal is not to view climate change as a local geographical problem to be solved by local or regional means, but instead to raise global awareness and seek global solutions in an integrated manner (e.g., Cash et al., 2006; Mazmanian et al., 2013).

5.4 Adaptation and Disaster Risk Management

In addition to the challenges spawned by the environmental issues of the new millennium, there is the deep concern that climate change and climate extremes might coincide with the occurrence of more natural disasters, e.g., sea-level rise, drought, flooding, and fires.

An analysis of six case studies of climate induced disasters in 2011 (see Figures 2 and 3, and Appendix 1), and their associated adaptation policies show disaster risk management as being the core adaptation strategy for climate change in the urban environment. FIG (2006[b]) demonstrates clearly how surveyors, although often as part of a multi-disciplinary task force, play a crucial, but many times unrecognised role in this field (e.g., Roberge, 2005). Figure 6 illustrates this role.

These issues are particularly relevant to small island developing states where economic and social vulnerability to natural disasters is greatly exacerbated Brigugilo (1995). In such cases there is the very real spectre of compressing more and more people into increasingly limited land areas that offer limited rights and protection to the owner. The surveyor is able to undertake a vital role in preparing for such eventualities either by identifying land parcels where such relocation can occur or by assisting in the development of new land tenure models that serve both the original land owner and future climate refugees. In reality, it is the surveyor with his/her multi-dimensional skills that enable the necessary spatial measurements to be made, land rights to be recognised and geospatial data to be analysed, so as to provide vital support to emergency response processes.

The surveyor, however, can have additional, but equally important functions in disaster risk management. The surveyor is able to take a wealth of land, social and environmen-

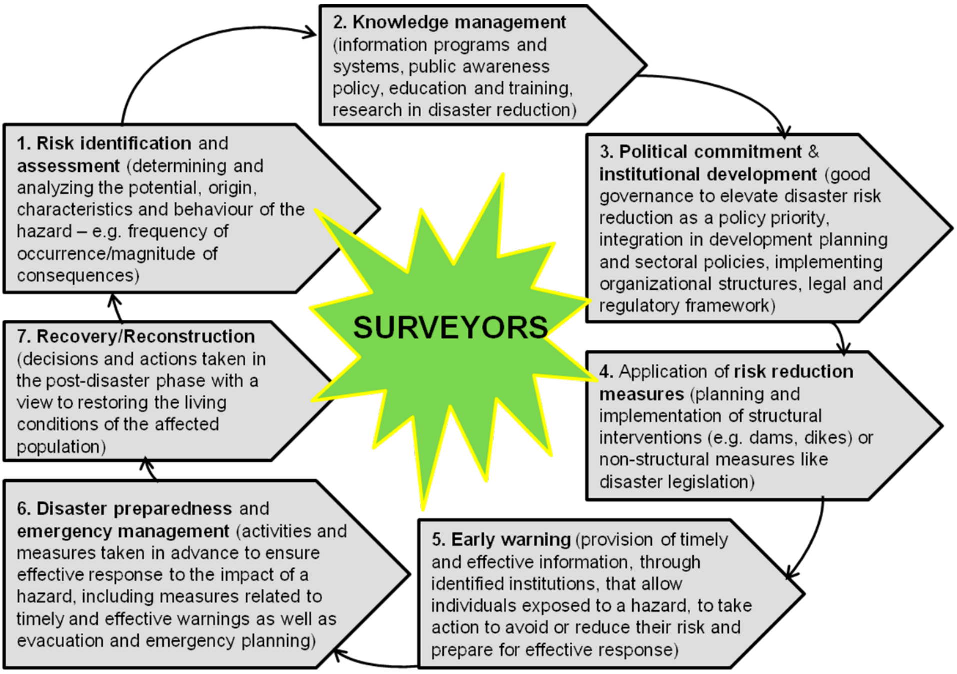


Figure 6: *The Surveyor's Role in Disaster Risk Management (FIG, 2006[b]; Boateng, 2012).*

tal data and integrate these into his/her GIS tools. The surveyor is then able to model the outcomes of potential disasters under various change scenarios thus producing a range of adaptation options. Furthermore, the surveyor can also facilitate the political commitment and institutional development needed to support disaster management responses (i.e., good governance so as to elevate disaster risk reduction as a policy priority, integration in development planning and sectoral policies, and the implementation of legal, regulatory and organizational structures).

5.5 Land Use Planning

Change and variability in land use by humans, and the resulting surface alterations are major but poorly recognized drivers of long-term global climate patterns. Between one-third and one-half of the earth's land surfaces have been transformed by human development. Research has documented the major role that such changes play in climate system variability (e.g., Pielke, 2005).

If solutions to climate change are to be found and implemented, it will require the participation of experts from a wide variety of societal sectors including transportation, energy, housing, law, agriculture and environmental education. Such change will require careful coordination and spatial planning, especially at a local level (Biesbroek et al., 2009). This, in turn, impacts upon the role of local governments or 'sub-national governments' (Puppim de Olivera, 2009). The importance of spatial planning is exemplified by the strong positive correlation between the reductions in transport related emissions and higher density of land use (Grazi and van den Bergh, 2008).

In cities with low levels of land administration capacity and poor land records, or poor enforcement of regulations, not only does urban growth lack appropriate controls but little tends to be done to prevent the construction of poor quality homes and buildings. This lack of direction in urban growth is typically a result of limited enforcement of land use policies, corruption, and poorly regulated land markets (World Bank, 2011).

Avoiding such outcomes is a planning and land use control problem. To help overcome such problems consultative approaches have been developed to managing growth in urban and peri-urban areas. Through the building of sustainable and spatially enabled land administration systems governments are better able to control access to, and use of, land. When these land administration systems are linked with identification of all hazard-prone areas there is a reduced likelihood of urban growth in hazard-prone areas. When coupled with effective building controls that are enforced, cities and the people within them will be more resilient to the impacts of climate change and natural disasters. However, additional innovative planning systems are needed. Angel et al., (2011), for example, after analysing 120 cities, developed a new 'making room' approach that avoided a detailed master plan approach in favour of localised expansion areas comprised of road networks, public spaces, utility services and secure land rights.

The Kyoto Protocol requires societies to respond to climate change by reducing greenhouse gas emissions ('mitigation') and coping with the changes ('adaptation'). IPCC (2007) outlines a comprehensive range of mitigation and adaptation options. Crucially, the underlying policy framework for such changes are seen to lie in institutional reform, land tenure and land reform, capacity building, integrated land-use planning, building codes, and national water policies.

However, the surveyor is not just a participant in land reform and land policies, his/her practical planning skills are far broader. In some jurisdictions, such as Australasia, it is the surveyor who is typically the designer of the layout of new housing settlements and with it, the location of the associated infrastructure. The surveyor can thus design housing allotments that are oriented so as to enhance thermal efficiency and protect environmentally sensitive areas.

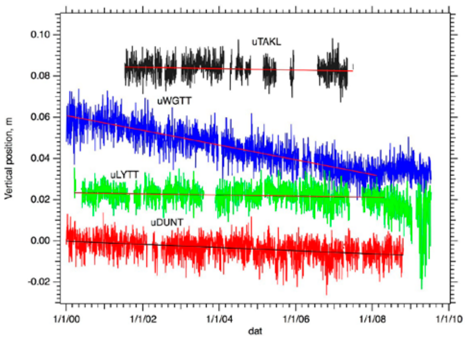
In the final analysis, however, people are not only the drivers of climate change but also the essential agents for redirecting development progress. Greenhouse gas emissions are really a proxy indicator for the social processes that drive them. What is needed is an institutional environment that empowers people and allows them to gain access to the resources they need for their well-being and the resilience of their livelihoods (UN, 2011). What are also needed are response measures coordinated across multidisciplinary teams of people that are based upon sound spatial planning and land management decisions. Surveyors, as land professionals, can deliver these land management services, in part through the use of "what if" scenarios modelled in GIS platforms.

6 PRACTICAL EXAMPLES

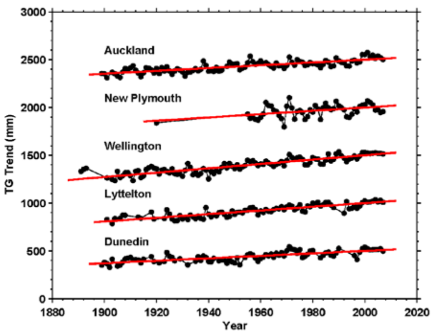
Example 1. Monitoring: *Assessing absolute sea level change in New Zealand.*

Description: New Zealand is a mid-latitude Southern Hemisphere country that sits astride the Australia and Pacific tectonic plates. The Southern Ocean current, a primary cooling mechanism for the global oceans runs between the southern tip of the country and the Antarctic land mass. New Zealand has four tide gauges with tidal records dating back to approximately 1900. These records, which are in a data sparse region of the world, are important in global sea level change analyses. However, the determination of absolute sea level change requires the separation of sea level change as determined from the tidal record from any land motion that may be occurring – the latter being determined from daily GPS solutions.

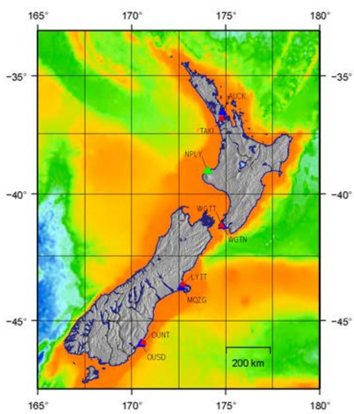
Contribution of surveyor: Undertaking the analyses of the tide gauge records, monitoring the local stability of the tides gauges using precise levelling techniques, determining the regional stability of the land to which the tide gauges are attached through the use of high precision GPS measurement techniques, and calculating absolute sea level change.



Continuous GPS data collected at the Auckland, Wellington, Lyttelton and Dunedin tide gauges.



Annual MSL data colleceted at the Auckland, New Plymouth, Wellington, Lyttelon and Dunedin tide gauges.



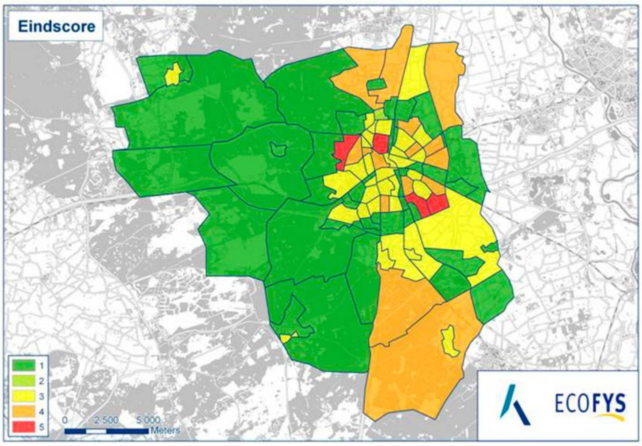
Location of the New Zealand tide gauges.

Source: Denys, P., Beavan, J., Hannah, J. (in preparation). Sea level rise in New Zealand: The separation of vertical land motion from the tide gauge record.

Example 2. Mitigation: *Reducing energy consumption and CO_2 emission in privately owned houses, Apeldoorn, The Netherlands.*

Description: The municipality of Apeldoorn, having more than 156.000 inhabitants is, amongst many other municipalities, searching for effective means to indicate the areas where private owners of dwellings are most willing to take energy efficiency measures. Apeldoorn has indicated that physical as well as social-economic aspects are important indicators. A map was made showing the most favourable neighbourhoods for taking energy efficiency measures.

Contribution of surveyor: Supporting the policy and decision makers with geographical information assembled from cadastral and other national geo-databases. These data include type of ownership, age of private owner, year of construction, and geographical location of houses.



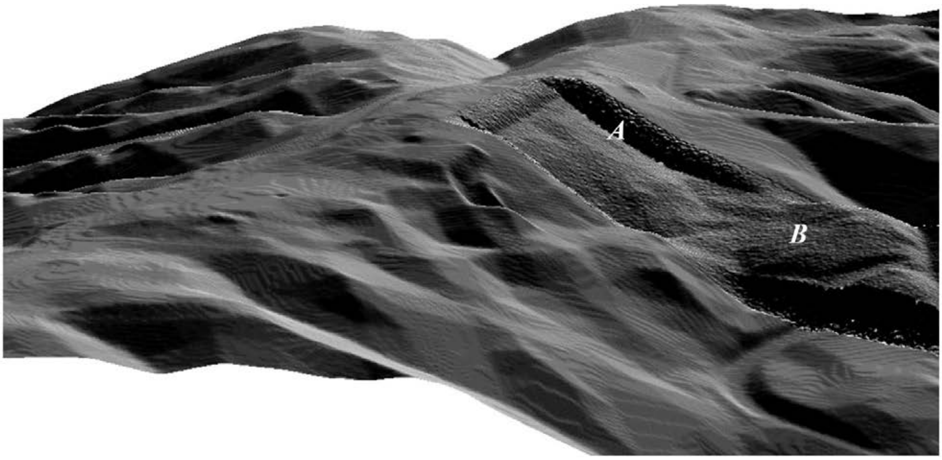
Chances of reduction of energy consumption and CO_2 emissions by taking energy efficiency measures by owners of privately owned dwellings. Red: highest chance Green: lowest chance.

Source: Vranken and Broekhof (2012).

Example 3. Adaptation: *Spatial modelling, simulating the effects of a landslide – Mount Carmel ridge, Israel.*

Description: Until recently, the characterisation of landslides for stability assessment has mostly been obtained from land surveys and, on occasion, airborne imagery. New techniques combine airborne imagery, LiDAR, geological field survey data and ground penetrating radar data in a GIS environment to enable an analysis of landslip risk. The LiDAR data provide a dense set of accurate topographic data that is easily collected and can cover wide expanses of land. In this instance a landslide simulation was based upon a 3rd degree polynomial where zones were defined to correspond morphologically with large shear strains – approximated by two straights lines running at right angles to the ridge line and corresponding to the lateral extent of the slip surface.

Contribution of surveyor: Collection of the airborne data and the LiDAR data. The integration of the data into a GIS package and then the resulting spatial modelling of outcomes.



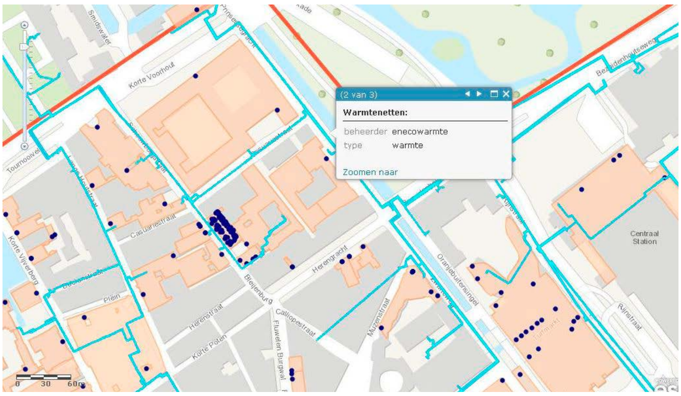
Shaded relief representation of the landslide simulation implemented on the LiDAR data:
A – depicts the displaced area; B – depicts the accumulated debris area.

Source: Dalyot et al., (2008)

Example 4. Mitigation: *Energy mapping: A spatial approach to energy consumption and energy generating potential, The Hague, The Netherlands.*

Description: The City of The Hague and the Dutch government have joined forces to develop a cost-effective, reliable and sustainable energy supply for their buildings in the area around Den Haag central railway station. Their strategy focuses on the joint property of national and local government buildings. It is considered to outsource the energy management, including local renewable energy, of 1.000.000 m2 office space to a private energy service company. An information tool was developed to explore new area-oriented possibilities in energy reduction and generation, to build a business case and to use it in the process of market consultation and tendering.

Contribution of surveyor: Merging cadastral and other national geo-databases for analysing property rights, building characteristics, subsurface heat networks and topography. Presenting the results in a web based GIS tool and enriching these with third party information such as energy consumption, geothermal and solar panel suitability maps.



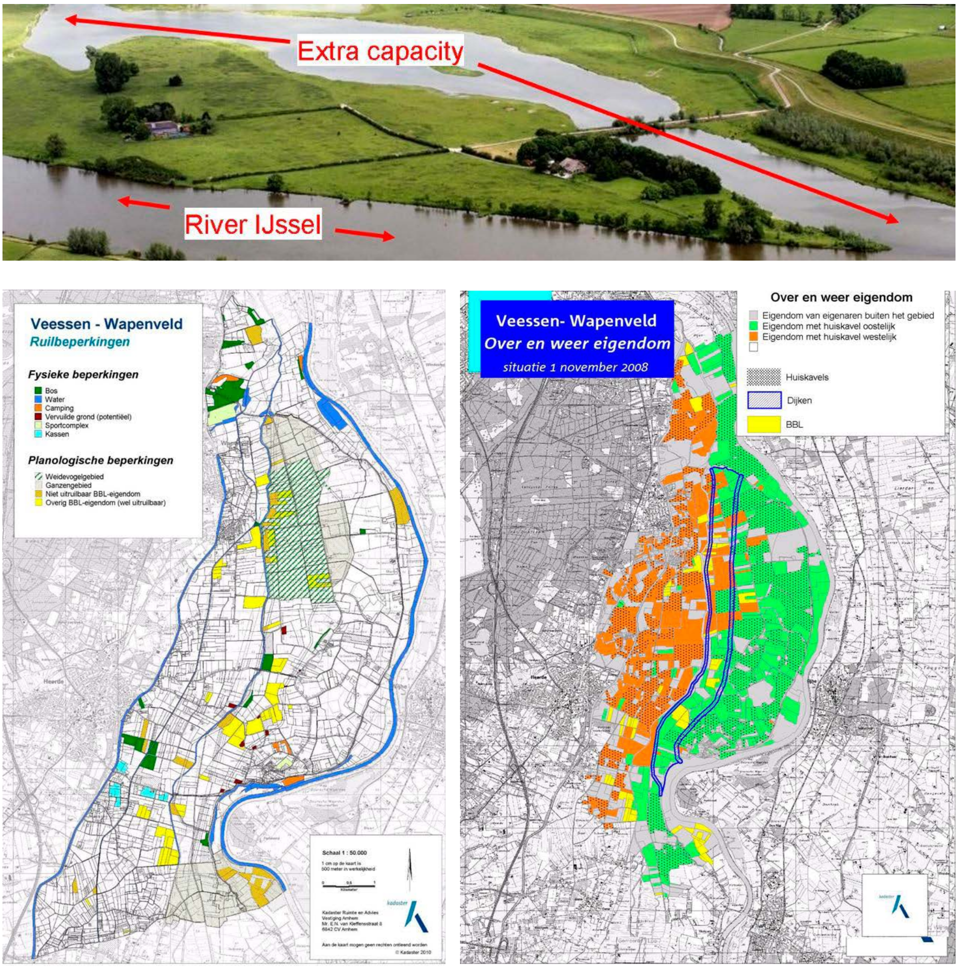
Images from the information tool showing the combined national and local government property (upper image) and the subsurface district heating network (lower image) in the city of The Hague.

Source: Van der Heide and Vranken (2013).

Example 5. Adaptation: *Consequences of increasing storage and flow capacity of the IJssel river, The Netherlands.*

Description: The goal of the national "Room for the River Programme" is to give the river more room to be able to manage higher water levels. Measures will be taken that give the river space to flood safely. Moreover, the measures will be designed in such a way that they improve the quality of the immediate surroundings. To reach these goal a carefully decision taking process is needed. This process is supported by analysing the consequences and restrictions for land use and ownership if an extra waterway is constructed.

Contribution of surveyor: Analysing parcels (ownership, location and characteristics), topography, zoning plans and mapping the results for several scenarios.



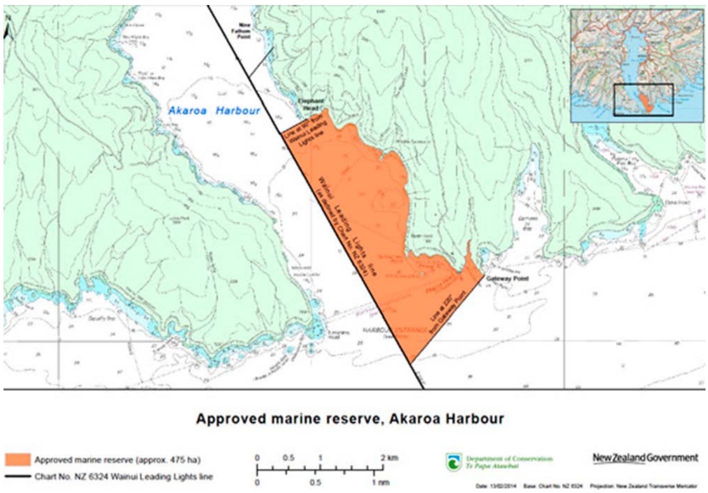
Extra storage capacity (upper), physical and zoning restrictions (lower left), parcel distribution and blockades (lower right) in the river IJssel.

Source: Project report by Kadaster, The Netherlands, 2010

Example 6. Monitoring: *Providing marine reserves, New Zealand.*

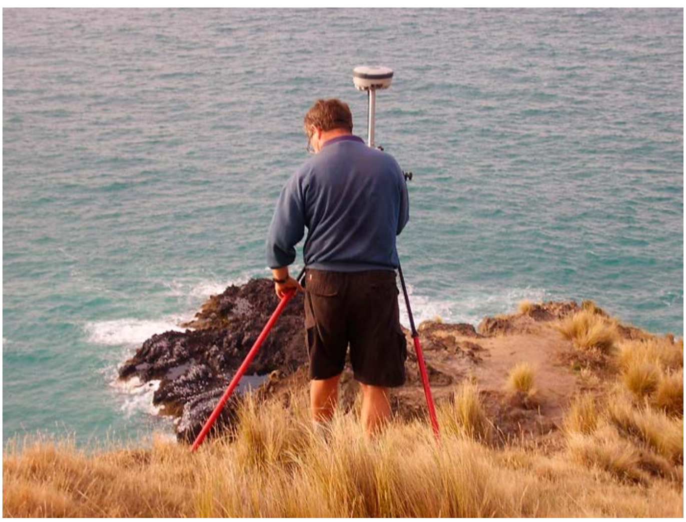
Description: Oceans are not only a vital source of food and nutrition for humans but are also a place for recreation. Providing reserves for monitoring these ecosystems where human impact is minimised allows scientists to better understand the complex inter-relationships that affect salt-water species in their natural habitat.

Contribution of surveyor: Analysing parcels (ownership, location and characteristics), topography, zoning plans, mapping the results and disseminating the boundary location.



The marine reserve, defined by surveyors, and then superimposed on hydrographic charts prepared by surveyors.

Source: Article in New Zealand Institute of Surveyors Newslink publication #213, May 2014.



Westland Branch NZIS Member Murray Marsh setting up at Akaroa.

Source: Photograph supplied by Coastwide Surveys Ltd., Hokitika, New Zealand.

Example 7. Mitigation: *Land consolidation to support the development of a new pumped storage hydro power station, Germany.*

Description: To further extend renewable energies in the Trier region the municipal energy supplier Trier Versorgungs-GmbH (SWT) is planning the construction of a pumped storage hydro power station (PSKW Rio) with an output of about 300 megawatt. The purpose will be to store as much energy from renewable energies in the region as possible without extensive cables and to provide it on demand. In times of low consumption and surplus of electricity, water is transported by an electrical pump from the lower storage basin to the higher. If later, at times of peak load, there is a lack of power, water can be let through a turbine from the higher storage basin into the lower and such be used for producing power. With pumped storage hydro power stations energy efficiencies of about 80 % can be reached. The basins of the projected PSKW Rio contain a storage volume of ca. 6 Mio. Cubic metres each. The overall land requirement of the project amounts to ca. 150 hectare.

Contribution of surveyor: Legal options for land consolidation in Germany are given by the land consolidation act. In a commercial project such as this, the concerns of the land-owners regarding the agrarian structure are taken into account as well as the need of the commercial corporation (in this case the energy supplier) for land for the project.

The land consolidation area is about 926 hectares and includes about 4,100 plots. The surveyor not only has an important role in the land consolidation process, but will also subsequently be used to provide the precise spatial measurements necessary to support the construction of the engineering infrastructure required for the project.

Visual of the planned lower storage basin [© SWT, BGHplan].

Source: Martin Schumann, ADD Trier und Heiko Stumm, DLR Mosel.

7 BUILDING PARTNERSHIPS

A former UN Secretary General observed that "*While many people are aware of the terrible impact of disasters throughout the world, few realize this is a problem that we can do something about*" (UN Publications, 2004).

Dealing with climate change and its associated impacts involves measurement, adaptation and mitigation. Surveyors, as measurement specialists, data integrators, and as a land professionals have a key role to play in all of these elements, particularly with respect to understanding and managing both risk and consequences. At the same time, surveyors recognise that the depth and breadth of the issues involved in climate change studies whether scientific, social, political, or environmental are of sufficient complexity that interdisciplinary cooperation is an essential prerequisite to finding robust solutions. Furthermore, and as outlined earlier in this report, partnerships at local, regional, national and international levels are essential if integrated, whole of community solutions are to be found.

Recognising the importance of these issues, it is incumbent upon surveyors to use their expertise both in taking a higher profile role in explaining to the wider public what climate change is all about and also in developing solutions. It is essential that surveyors, as experts in land administration and management, take a leading role in addressing the climate change challenge in the wider context of sustainable land governance. In this regard The International Federation of Surveyors (FIG) is committed to helping UN agencies such as UN- FAO and UN-Habitat, and the World Bank influence the global agenda in relation to the climate change challenge and designing measures for appropriate action.

One immediate area of co-operation lies in identifying land ownership and land use in disaster response situations. While land is essential for emergency shelter and protection of displaced persons, poor selection of such sites, or poor responses, typically leads to long term conflict or tenure insecurity. In addition, land is necessary for restoration of livelihoods. Land grabbing after a disaster is a key risk to effective protection and emergency shelter activity. Humanitarian agencies are therefore confronted with land issues as they undertake emergency shelter and protection activity. These factors must be taken into consideration when preparing for such disasters (UN-HABITAT, 2010).

Additionally, the ability to identify clearly individual land parcels and the rights attached to these parcels are essential elements of the reconstruction phase that follows the immediate humanitarian effort of saving lives and providing immediate relief. This reconstruction phase requires re-establishing the situation of legal rights to land and properties and the reconstruction of buildings and infrastructure in secure locations. Surveyors are well able to partner with aid agencies in such processes.

A further area of cooperation, typically with the World Bank, relates to building and using land administration systems with a view towards identifying levels of potential disaster risk. Such risks can be identified as area zones in the land use plans and land information systems with the relevant risk assessments and information attached. Such disaster risk zones may relate to sea level rise, earthquakes, volcano eruption, flooding, draught, hurricanes, etc. By combining the disaster risk information with the relevant information on land tenure, land value, and land use the necessary risk prevention and mitigation measures can be identified and assessed in relation to legal, economic, physical, and social consequences.

In terms of their spatial measurement skills surveyors are already an integral part a teams that assess and analyse sea level rise (e.g., Hannah, 2004). There exists opportunity, however, particularly for surveyors from developing nations, to ensure that local tide gauges and tide gauge monitoring systems are fully integrated into global reference frames. This will require a combination of local levelling and the use of GNSS technology.

In total and in order to go down this integrated and participatory road of measurement, adaptation and mitigation of climate change, all segments of the community will need to part of the process. This will require a strong commitment from the surveying community to promoting sustainable development in such a way that it focuses simultaneously on economic growth, social progress, and environmental considerations. It would be a gross failure of leadership for the profession not to take the necessary initiatives to do this. As has been so aptly pointed out by The Economist (2010), "*Development needs to be climate ready, even if it cannot be climate proof*".

8 CONCLUSIONS

Climate change, with its resulting impacts on the global community, is an issue that is pivotal to the future well-being of the global community. For this reason it has an important place in the agenda of agencies such as the United Nations and the World Bank. Many physical variables and climate related changes can be measured and/or detected – a process in which surveyors have, and need to continue to participate.

The core data sets associated with climate change studies, i.e., those with a long time series of data, have been associated with *in situ* measurements and measurement systems. These include trigonometric data, tide gauge data, meteorological data, ocean temperature data, gravity data and ice core data. In recent decades, however, these have been extended to include a full suite of satellite based earth observation data.

Historically, it has been the surveyor's task to construct and maintain the coordinate based reference systems (i.e., position and height) that have allowed these data to be integrated into regional, national and global data bases. Surveyors have been responsible for collecting tide gauge data and designing the high precision levelling networks required when such tide gauges have been connected to local bench marks. These tide gauge data, which have then formed the basis of the Mean Sea Level (MSL) height datums used for the design of local infrastructure and for national mapping, now form the basis for monitoring global sea level change. In nations where land administration systems exist, surveyors have had the task of defining the size and the location of the parcels of land that form part of the system. They have then played an integral part in administering those systems.

However, in looking to the future, the leading question has little to do with whether or not climate change will happen but rather the quantum that can be expected in coming decades, the mitigation strategies that can and should be used, and the adaptation processes that may be required. As the world faces the climate change challenge, it is with regard to mitigation and adaptation that surveyors are increasingly leveraging their skills. In particular, surveyors are designing and developing new land administration systems that are fit-for-purpose and that are aimed at all tenures along a continum of land rights. Such systems are essential if property rights are to be fully understood and tenure security respected – both being essential elements in affecting climate-sensitive changes to existing land use patterns. These efforts need to be continued and extended.

Having designed and developed new land administration systems, surveyors are now integrating social, economic, environmental and geographical data into these systems so as to support the spatial analyses needed when "what if" climate adaptation questions are asked. For example, what geographic locations within a particular region might be best suited for the resettlement of climate refugees? Who has rights in that land and what are those rights? Is the land suitable for supporting the necessary infrastructure? Answering questions of this nature lead to other functions of the surveyor, namely, disaster risk management and land use planning. Here the breadth of the surveyors' skills become apparent, for not only can the surveyor assess adaptation and mitigation options but can also undertake the essential precise spatial measurements needed if/when the required infrastructure is to be built. In reality, it is this breadth of knowledge and skill that makes the surveyor such an important part of overall climate monitoring, adaptation and mitigation processes. It is important that surveyors not only recognise the uniqueness of their position, but that they continue to develop and enhance their skills in such areas, for in so doing they will provide an important service to the global community.

In many regards, surveyors are the custodians of the enabling technologies that are critically important to the future of the human race. However, the depth and breadth of the issues involved in climate change studies (whether scientific, social, political, or environmental), are of sufficient complexity that the surveying community will be but one player amongst many if robust solutions are to be found. Furthermore, partnerships at local, regional, national and international levels will be essential if integrated, whole of community solutions are to be found. As land professionals, surveyors have the opportunity be at the forefront of partnering with communities, professional groups, and global agencies in order to deliver these outcomes. They need to seize the initiative to ensure that this happens.

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APPENDIX 1:
EXAMPLES OF CLIMATE INDUCED DISASTERS IN 2011

Case Study 1: 2011 Flooding in Genoa and Turin, Italy

Brief news about the flooding	Evidence of flood devastations
Date: November 2011 Northern Italy inundated many dead. Heavy rain with insufficient runoff channels has apparently been the cause of this catastrophe. Damage to property and disrupted business will take months to even calculate. Seven people have been killed in Genoa after flash floods devastated the port city. Thousands of people in low-lying areas near Turin have been told to leave their homes, while the city's schools, as well as those in Milan, were ordered to close. **Source:** World disaster report, November, 2011	 Flooding at Turin, Italy (Photo: Fausto Guzzetti).  Flooding at Genoa, Italy (Photo: Black Panther).

Case Study 2: 2011 Flooding at Hubei and Zhejiang, China

Brief news about the flooding	Evidence of flood devastations
Date: June 2011 Torrential rain began to lash Hubei, Hunan, Jiangxi, and Anhui provinces. The rainfall triggered floods and landslides which had forced over 55,000 people to evacuate their homes. Previous heavy rainfall had already caused widespread destruction in Xianning, leaving dozens dead. The Ministry of Civil Affairs says flooding and landslides triggered by an earlier two rounds of rainstorms had left 105 people dead, 100 injured and 63 more missing in the south over the past 10days. **Source:** Global time.CN, June 2011.	 Flooded village at Hubei (Photo: Global time.CN).  Flooded twon at Zhejiang (Photo: Global time.CN).

Case Study 3: 2011 Flooding at Pennsylvania & Bringhamton, USA

Brief news about the flooding	**Evidence of flood devastations**
Date: September, 2011 Flood water in New York, Pennsylvania. Officials in north-eastern Pennsylvania called for a mandatory evacuation of more than 100,000 residents living along the Susquehanna River on Thursday due to expected flooding. Emergency management officials in Broome County ordered additional evacuations early Thursday for Binghamton neighbourhoods near where the Susquehanna and Chenango rivers converge. Mandatory evacuation orders were also issued for the neighbouring villages. **Source:** The Blaze (Associated Press, AP), September, 2011.	 Flooding at Pennsylvania, USA (Photo: AP).  Flooding at Bringhamton, USA (Photo: AP).

Case Study 4: 2011 Flooding at Sindh Province, Pakistan

Brief news about the flooding	**Evidence of flood devastations**
Date: September, 2011 Severe floods in Sindh: Torrential rains have struck southern Pakistan in recent days, causing at least 209 dead so far and 5.3 million displaced in the province of Sindh. Rescue operations and emergency efforts are slow due to the difficult weather conditions and flooded lands. In 2010, Pakistan's worst flooding in nearly a century affected more than 14 million people and left at least 1,600 dead in the same area, UN said. The Chinese embassy in Pakistan has promised support for 4.7 million dollars to deal with the emergency and help the victims in Sindh. Prime Minister Yousaf Gilani has confirmed that about 700 thousand houses are damaged; at least 150 thousand people who have sought refuge in emergency centres are in need of immediate assistance. **Source:** AsiaNews, August, 2010.	 Flood Victims at Sindh Province (Photo: Reuters).  Call for rescue at Sindh Province (Photo:Reuters).

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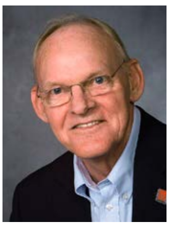

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FIG PUBLICATIONS

The FIG publications are divided into four categories. This should assist members and other users to identify the profile and purpose of the various publications.

FIG Policy Statements

FIG Policy Statements include political declarations and recommendations endorsed by the FIG General Assembly. They are prepared to explain FIG policies on important topics to politicians, government agencies and other decision makers, as well as surveyors and other professionals.

FIG Guides

FIG Guides are technical or managerial guidelines endorsed by the Council and recorded by the General Assembly. They are prepared to deal with topical professional issues and provide guidance for the surveying profession and relevant partners.

FIG Reports

FIG Reports are technical reports representing the outcomes from scientific meetings and Commission working groups. The reports are approved by the Council and include valuable information on specific topics of relevance to the profession, members and individual surveyors.

FIG Regulations

FIG Regulations include statutes, internal rules and work plans adopted by the FIG organisation.

List of FIG publications

For an up-to-date list of publications, please visit
www.fig.net/pub/figpub

ABOUT FIG

International Federation of Surveyors is the premier international organization representing the interests of surveyors worldwide. It is a federation of the national member associations and covers the whole range of professional fields within the global surveying community. It provides an international forum for discussion and development aiming to promote professional practice and standards.

FIG was founded in 1878 in Paris and was first known as the *Fédération Internationale des Géomètres* (FIG). This has become anglicized to the *International Federation of Surveyors* (FIG). It is a United Nations and World Bank Group recognized non-government organization (NGO), representing a membership from 120 plus countries throughout the world, and its aim is to ensure that the disciplines of surveying and all who practise them meet the needs of the markets and communities that they serve.

Climate change is widely viewed as one of the most pressing global environmental issues of our time. While the reliable assessment of the quantum of change requires a long history of accurate measurements of ocean, earth and atmospheric data, preparing humanity for future life will require comprehensive strategies for adaptation and mitigation. Surveyors, as measurement specialists, data integrators and land professionals have a vital role to play in these activities.

It is the surveyor who, as a specialist in spatial measurements, has traditionally established and maintained the coordinate systems that have been used for measuring and monitoring global change. It is the surveyor who is the custodian and a user of the digital tools and the digital databases needed in spatial analysis and urban planning. These allow the surveyor to analyse a range of land use options and so give well informed policy advice to decision makers. Furthermore, the surveyor is skilled in the definition of land boundaries, having a detailed knowledge of the associated tenure rights (whether formal or informal). These are vital inputs if land use options, capable of withstanding climate change, are to be designed and adopted – thus vastly improving climate change outcomes for the vast majority of the world's peoples.

The training of surveyors with their diverse skill set cover both the natural and social sciences, enabling them to bridge the divide that often exists between these two broad discipline areas. However, surveyors recognise that the depth and breadth of the associated scientific, social, economic, political and environmental factors are of sufficient complexity that interdisciplinary cooperation is essential if robust, whole of community solutions are to be found. Surveyors have the capacity and the desire to assist the global community find such solutions.

ISBN 978-87-92853-26-4 (printed) • ISBN 978-87-92853-27-1 (pdf)