CoastAdapt

Climate change and contaminated land

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Impact Sheet 10

Contents

Introduction to climate change and contaminated land in Australia

Australia is at risk from the impact of anthropogenic (human-induced) climate change, both now and in the future. Some of the direct impacts of climate change, especially in coastal zones, include sea-level rise, extreme weather events, increased erosion, increases in temperature, and greater rainfall variability. Recent reports indicate that there will be rapid and extensive changes to global ecosystems with unknown consequences for human populations (IPCC 2007).

This document identifies the likely impacts of climate change in relation to contaminated land. It aims to stimulate debate on the impacts that climate change will have on the development and management of contaminated land sites in Australia.

Climate change impacts on contaminated land in Australia will affect a number of land uses ranging from industrial facilities, landfill operations, industrial waste storage, tailings dams and other forms of use that have resulted in contamination of soil.

The assessment, remediation and management of contaminated land are very proscriptive. The national body, the National Environment Protection Council (NEPC) developed National Environment Protection Measures (NEPMs) to protect and manage particular aspects of the environment, including contaminated land. The goal of the NEPC is to establish national consistency in guidelines and methodologies for the assessment of contaminated land which are outlined in the National Environment Protection (Assessment of Site Contamination) Measure 1999 (2013 amendment) (Australian Government 2013)

The assessment of contaminated land is made on risk-based criteria, which quantify potential ecological or human threats from contaminants via exposure pathways. The risk is assessed on a site-specific basis, with the assessor gauging the risk by considering the degree and nature of contamination, the available receptors, the pathways to the receptors and the rates of exposure.

The NEPM outlines investigation or screening levels, which are used to determine whether further site-specific risk-based approaches or management are required for the intended land use (Australian Government 2013). As a result, predetermined levels of risk of exposure and toxicity, as well as pathways, are used to assess contaminated land. Historically, contaminated land experts and climate change scientists have not collaborated on the likely impacts of climate change on the assessment process for contaminated land (Schiedek et al. 2007).

Impacts of climate change on contaminated land

Temperature change

Temperature changes linked to climate change are well documented as affecting many ecosystems. Carbon dioxide, along with other anthropogenic gases in the atmosphere, produces a greenhouse effect, trapping heat and warming the Earth's surface and atmosphere. The Garnaut Report (2008) predicted a national temperature increase of between 0.4 °C and 1.8 °C relative to 1990 levels by 2030. Coastal areas will see a smaller increase, between 0.7 °C and 0.9 °C. It is important to note that these projected changes do not account for climate change mitigation strategies.

The Fifth Assessment Report (AR5) prepared by the Intergovernmental Panel on Climate Change (IPCC) predicts that under a scenario where no action is taken (a low emissions scenario or RCP2.6), global temperatures could increase by up to 1.7 °C by 2100, relative to 1986-2005 temperatures, and up to 4.8 °C under a scenario where no or little action is taken (a high emissions scenario or RCP8.5) (IPCC 2013). These trends are illustrated in Figure 1 below.

The waste industry recognises that it is in a unique position to influence the amount of greenhouse gases (GHGs) emitted. To this end, the waste industry has been improving the capture and in some cases re-use of GHGs such as methane. An effort by the waste sector in 36 industrial nations has resulted in a decline in GHG emission by 14-19%, predominantly due to methane capture (ISWA 2009).

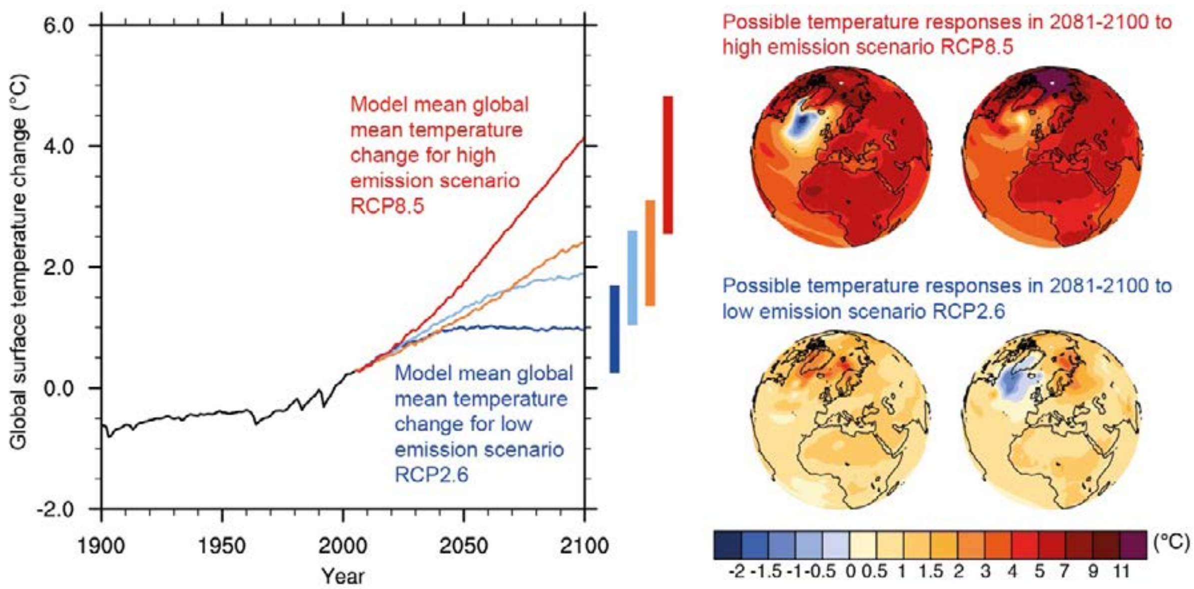

Figure 1: Model mean global temperatures of RCP2.6 and 8.5. Source: Collins et al. 2013 (IPCC Fifth Assessment Report, Working Group 1, Chapter 12, Figure FAQ 12.1-1).

Higher temperatures are also known to increase the toxicity of certain chemical pollutants as well as increasing their uptake, caused by an increased metabolic rate brought on by higher temperatures (Schiedek et al. 2007).

Kennedy and Walsh (1997) demonstrated that raised aquatic temperatures would increase the uptake of pollutants by organisms due to changes in their ventilation rates and a decrease in oxygen solubility in the aquatic ecosystems.

The increase in global temperature is likely to have a direct impact on landfills and waste containment systems, and more research is required in this area to assess the extent of these impacts. Positive impacts may include greater production of renewable energy through methane production and capture, which can conversely be a negative impact in facilities which still 'flare off' and do not capture methane.

The challenge in quantifying the likely impacts is the dynamic nature of climate change. Thousands of studies are underway to assess the current extent of impacts, predict future impacts, and find ways to mitigate the impacts of climate change. The AR5, produced by the IPCC, reviews data from around the world to provide a clear and current view of the state of scientific knowledge relevant to climate change.

Increasing global temperatures will push many species to the limits of their tolerance to heat. Species with lower thermal tolerance limits and those unable to adapt through physiological mechanisms such as temperature-mediated gene expression may suffer the most stress (Somero 2005). The loss of any species can significantly change the structure and function of ecosystems (Schiedek et al. 2007) with unpredictable follow-on effects for environmental and economic relationships.

Increases in global temperatures will impact contaminated land in a number of ways including site remediation. The rate of remedial action in soil can often be influenced by microbial activity, which will be affected by changes in global temperatures. In addition, the rates of volatile substances being released into the atmosphere will be directly influenced by increases in global temperatures and already-high levels of premature deaths from air pollution will increase.

Sea-level rise

Sea levels are rising as a result of increases in global temperature. Higher temperatures cause ice sheets and glaciers to melt, contributing to the volume of oceans. As water is heated it expands and increases in volume and over the entire globe this thermal expansion can have significant impacts. The majority of sea-level rise expected will be a result of thermal expansion due to global warming, and not as a result of the melting ice sheets and glaciers (IPCC, 2013).

Sea levels can also vary spatially due to local temperature differences, ocean circulation, salt concentrations in the water and land movements (Garnaut 2008). Decision-makers considering contaminated land sites should be aware of the regional factors that may influence local sea levels.

The AR5 produced by IPCC reveals that between 1901 and 2010 sea levels rose at an average rate of 1.7 mm per year; while between 1993 and 2010 sea levels rose at an average rate of 3.2 mm per year (IPCC 2013), as illustrated in Figure 2. Projections for sea-level rise in the report show an increase of up to 0.98 m above pre-industrial levels by 2100 if no action is taken in response to climate change (a high emissions scenario) (Figure 2 in red).

The Australian Government's *Climate Change Risks to Australia's Coast* assessment (Department of Climate Change 2009) presents a sea-level rise of 1.1 m by 2100, while identifying the need for a periodic review of risk assessments and policies to reflect new research findings.

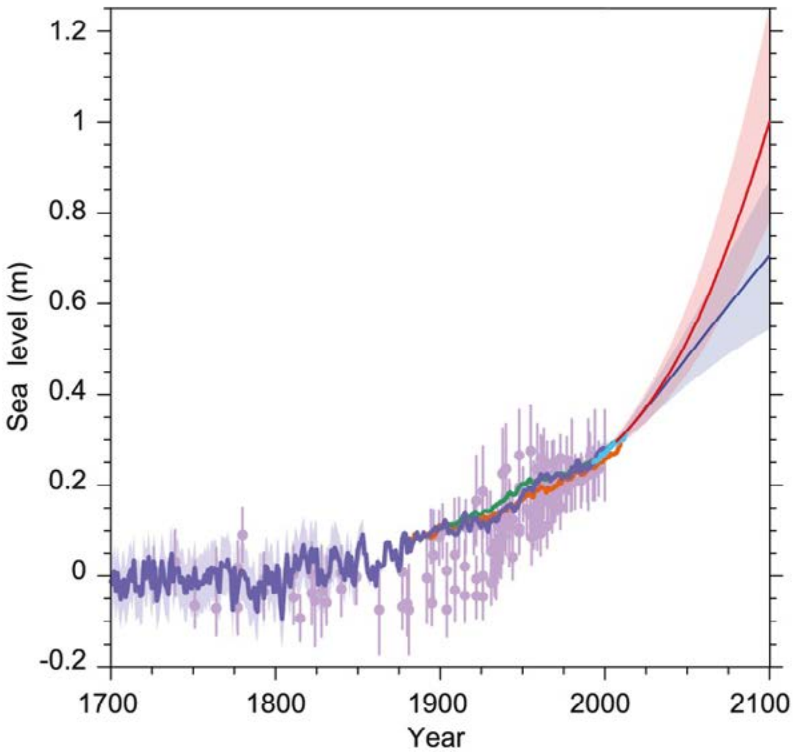

Figure 2: Compilation of palaeo sea-level data, tide gauge data, altimeter data, and central estimates and *likely* ranges for projections of global mean sea-level rise for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values. Source: Church et al. 2013 (IPCC Fifth Assessment Report, Working Group 1, Chapter 13, Figure 13.27).

The rising sea levels predicted as a result of climate change will have significant impacts on the natural and built environment of Australia's coastal zones. Many coasts will become periodically inundated as a result.

A 1.1 metre sea-level rise would put 30,000 km of roads at risk across Australia, while housing and infrastructure currently valued at more than $226 billion would also be at risk (Department of Climate Change 2009). Likewise, the design criteria of landfills, contamination containment cells and other engineered facilities to contain waste or contaminants will be irreversibly altered by climate change.

With the increased risk of flooding, contaminated land sites in coastal zones will be at higher risk of inundation. This brings a greater risk of contaminants being mobilised in floodwater and sediments, which could then reach freshwater and marine environments (Schiedek et al. 2007).

The increase in groundwater levels will have a direct influence on the mobility of contaminants and subsequent remediation techniques, as well as groundwater remediation projects.

Many waste containment structures, either engineered landfills or smaller on-site containment cells, are all designed according to local groundwater conditions. If these conditions are in a state of flux due to climate change, decision-makers must allow for adaptation in their designs of any containment structure containing waste or contaminated soil, as well as remediation strategies involving groundwater.

Other climate change considerations with the potential to impact contaminated land are contaminant pathways, climate, bioavailability and remobilisation (Schiedek et al. 2007).

Other factors

Climate change is predicted to result in less frequent but more extreme weather events including storms, cyclones and heatwaves. Such events may lead to catastrophic damage to the natural and built environment, with an increase in the severity of winds, floods, and bushfires.

Northern Australia is subject to tropical cyclones and tropical lows, which can bring extremes of rainfall and wind speeds. While studies predict climate change to result in a reduction in the number of cyclones, they do predict an increase in their intensity (Stephens and Ramsay 2014).

There is also evidence of a poleward shift in the extent of tropical cyclones toward the south (Department of Climate Change 2009). This could put more populous regions of Australia at risk of the effects of tropical storms.

Bushfires are also predicted to increase in number and severity. The number of days having extreme fire weather is expected to increase by 100 to 300 days per year by 2067 (Garnaut 2008).

Design and management of landfills, contamination containment cells and other engineered designed facilities used to contain hazardous waste and contamination need to be adapted and procedures will need to be implemented to ensure the sites within coastal zones will be able to adapt to the predicted impacts.

Contaminated land within coastal zones can present a risk to natural environments when subjected to severe erosion mechanisms. Toxic chemicals stored in hazardous waste facilities, tailing dams, in soils and present in deposited sediments within catchments can be mobilised as a result of erosion and transported to more sensitive ecosystems (Schiedek et al. 2007).

Climate change is also likely to result in an increase in the size and energy of waves reaching the shores. This, combined with effects of sea-level rise will result in chronic coastal erosion and shoreline recession (Department of Climate Change 2009). The erosion of contaminated land sites subject to coastal erosion could see the direct contamination of marine habitats if proper management is not in place. In extreme cases relocation of contaminants may be required.

Climate change is predicted to cause drought throughout much of Australia, while rainfall events are expected to become more extreme (Department of Climate Change 2009). Such variability in rainfall can have several impacts. Groundwater recharge rates will be decreased as much of the high-intensity precipitation will result in overland flow and surface runoff during heavy rainfall events. Increased erosion will put containment facilities at risk of failure which will risk polluting the environment and threaten human health. The changes in rainfall regimes, sea-level rise and groundwater conditions will all influence the economic and environmental value assessment of remediation projects in coastal Australia.

Adaptation

Decision-makers planning for climate change adaptation in coastal zones need to identify the vulnerability of the areas in question. The *Garnaut Climate Change Review 2008* identifies the three components contributing to the vulnerability of a system to climate change as:

1) ***exposure*** to changes in the climate system,

2) ***sensitivity*** to those exposures, and

3) ***capacity to adapt*** to the changes to which they are sensitive (Garnaut 2008).

These components are illustrated in Figure 3.

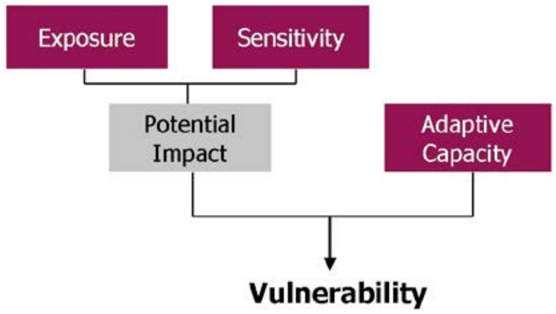

Figure 3: Components of Vulnerability to Climate Change. Source: Allen Consulting 2005.

Once the vulnerability of a system has been identified, decision makers can begin the process of adapting contaminated land sites to reduce both the exposure and the sensitivity of the site.

The impacts of climate change have been shown to have a direct or physical impact on contaminated land, especially on the containment facilities storing waste or contaminated land or sites with residual contamination present. Further modeling of hydrological regimes in coastal Australia will be required to determine the impacts of climate change on remediation and assessment of contaminated land. Remediation strategies will need to be cognisant of long-term climate and hydrological changes that inevitably will occur in our coastal regions.

The next section outlines the impact of climate change on the process of contaminated land assessment and management.

Impact of climate change on risk assessment of contaminated land

Contaminated land experts use conceptual site models to quickly assess the dynamics of a system in order to understand the pathways and linkages of a site. These models provide a snapshot of the site to aid the practitioner to focus on which pathways are available to receptors on-site.

Future assessments will include climate data on the expected rainfall, wind intensity, evaporation rates or expected groundwater levels or expected levels of salinity, sodicity or other physio-chemical stressors on the ecosystem (including human activity). As with most disciplines in the broader field of environmental science, assessment of contaminated land (which includes pollution of both marine and fresh water) uses mechanisms to characterise or simplify situations in order to make judgements or quantify the level of risk to ecological and human receptors on a given site.

Contaminated land professionals will use data from toxicity trials to assess the risk of contaminants. The data collected in the trials may have been from previous decades; however, management decisions on the toxicity of a contaminant are made with the best available data.

In the assessment of contaminated land there are levels or tiers of assessment. Tier 1 levels of assessment often use generic or standardised data, such as investigation levels in the NEPMs to assess the risk of an effect of a contaminant on a receptor, ecological or human. Tier 2 or 3 levels of assessment will often use risk assessments to develop site-specific criteria to assess the levels of risk. As would be expected the Tier 2 level of assessment includes the ability to develop criteria using toxicity data specific to the site. In these assessments there is an ability for the practitioner to include climate change adaptation data or increase safety margins to include the increase in variability of the data. Unfortunately, at this point in time, the contaminated land industry predominantly uses Tier 1 levels of assessment, and therefore, adaptation data are not commonly included in contaminated land management.

As demonstrated above, the interactions between contaminants and the on-site receptors are often judged based on historical knowledge of the interactions of contaminants and the receptors over the past 10 or even 20 years. Toxicity assessments of the myriad of contaminants among the plethora of receptors are a costly and time-consuming process. The Society of Environmental Toxicology and Chemistry (SETAC) has discussed this topic at length and is concerned with the number of new chemicals being produced and the level of toxicity on organisms in the environment or the food web, with potential for impact on human health.

As environmental scientists we would like to evoke the precautionary principle on all new chemicals to ensure that the manufacturers of these chemicals can demonstrate that the chemicals are not just 'safe' for consumption, but the level of toxicity on all organisms and the environment is know prior to sale of the chemicals (UNESCO 2005).

A primary concern is that our science of toxicology, chemical fate transport, bioavailability and other scientific disciplines which contribute to the science of contaminated land as well as the surrounding policy and legal framework will be unable to adapt to climate change in a timely manner.

Both past practices of safe containment of potentially hazardous contaminants within sites as well as current assumptions and risk hazard calculations may be invalid in future climate change scenarios.

The impacts of climate change have the potential to destabilise the safe containment of past hazardous contaminants, as well as present assessments of such contaminants. Adapting the discipline of assessment and management of contaminated land sites to the risks of climate change will be challenging for decision-makers.

Whereas other changes on contaminant behaviour are more definitive, metalloid uptake in soil has a direct correlation with pH and salinity of the soil, which will be directly influenced by climate change (González-Alcaraz et al. 2015).

Therefore, there are extremes of climate change that affect assessment of contaminated land. In 2011, the Society of Environmental Toxicology and Chemistry (SETAC) held a workshop on the potential influence of climate change on the foundations (chemical fate, mechanistic/population ecotoxicology) and applications (human and ecological risk and injury assessments) of environmental toxicology and chemistry (Landis et al. 2014). From this workshop four consensus observations emerged:

1. The mitigation or adaptation to global climate change may have as much influence on the fate, transport or distribution of contaminants as global climate change itself (Gouin et al. 2013; Landis et al. 2014).
2. Climate change has the ability to increase the risk to human health by its interactions with contaminants. Climate change can affect the toxicity of chemicals directly in terms of changes in physiochemical interactions. Climate change can affect the ability of an organism to adapt to climate change. The increased stress on ecosystems as well as organisms can lead to changes in their ability to adapt to changes in toxicity of chemicals.
3. The decrease in the ability of organisms to adapt to toxicity of chemicals can be related to climate-related mechanisms such as temperature regulation, water regulation and responses to acidification or salinity. Population or ecosystem fitness levels can be limited or enhanced, leading to potential influences on human health (Landis et al. 2014). Human health and health of ecosystems will therefore be influenced by global climate change. Classical risk assessment of contaminated land is linear and static; exposure and toxicity are well documented and effects on organisms and ecosystems well understood, albeit in a certain time frame. The way contaminated land is assessed in Australia was recently upgraded. The new NEPMs, released in 2013, include an update of toxicity levels and exposure rates for contaminants, developed over a ten-year period.
4. Global climate change is not linear or fast acting, it is slow and variable. The ecological impacts of global climate change are patchy, isolated and affected by the plasticity of populations (Landis et al. 2014).

It is obvious that the classical way we assess or calculate the stressors on human health or the environment are no longer in step with the changing landscape. Human and ecological risk assessment of toxicity, exposure assessment and assessment of contaminated land all need to be adaptive to climate change. Baseline conditions derived from 30 years of environmental data, without the influence of climate change or anthropogenic forcing being taken into account, is no longer viable in estimating the risk to human health or the environment (Landis et al. 2014; Australian Government 2013).

Schiedek et al. (2007) illustrates the complexity of both climate change and the interactions with ecosystems and contaminants in Figure 4 (Schiedek et al. 2007).

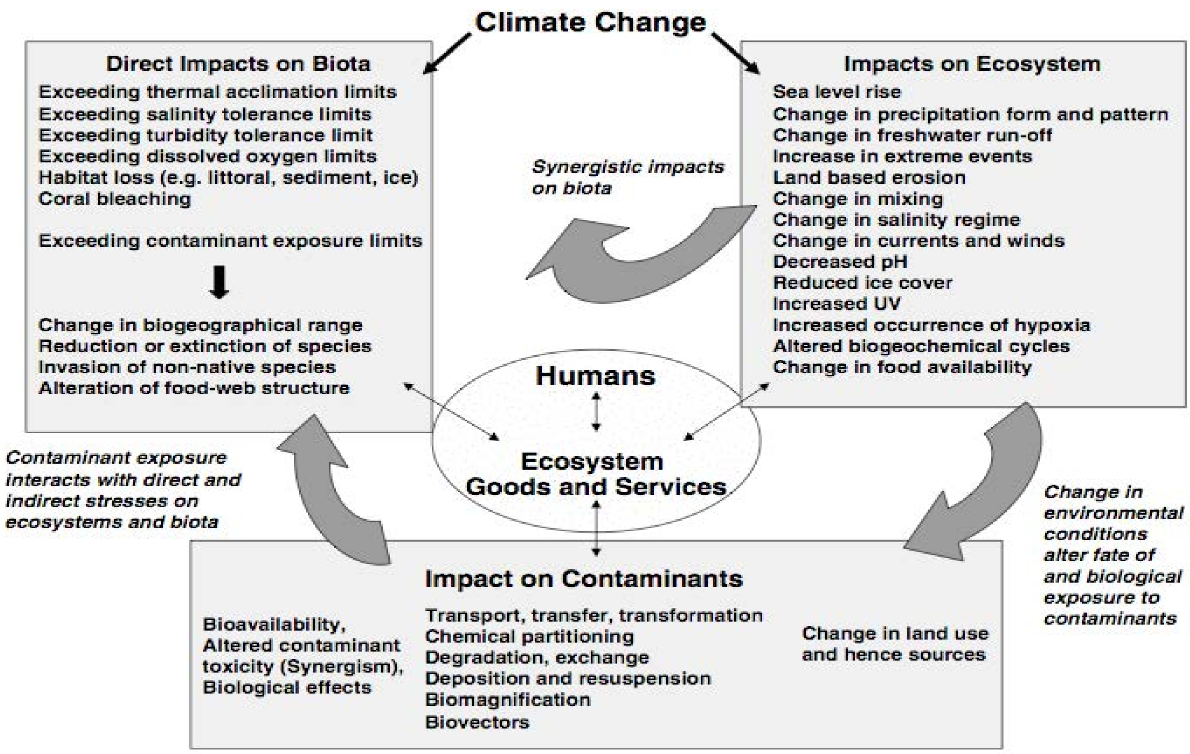

Figure 4 : Overview of climate change impacts on ecosystems and contaminants. Source: Schiedek et al. 2007.

The scientific community now recognises the challenges of assessing the impacts of contaminants on human health and ecosystems in the context of global climate change. An overview of impacts of global climate change will need to include the complex changes of interactions between receptors and contaminants (Schiedek et al. 2007).

In addition, further urgent attention is required to model the impact of sea-level rise on coastal zone environmental remediation. The contaminated land sector needs to increase research and development in order to understand and reduce the negative impacts of climate change on current remediation methods.

Geochemical changes resulting from climate change and hydraulic shifts will have implications for bioremediation, natural attenuation or passive remedial measures, as well as long-term protection of legacy sites.

Conclusions

Climate change will impact contaminated land in coastal regions, landfills and waste storage facilities in a number of ways. The more direct influence of climate change will be how changes to temperature, sea levels and extreme weather events change the level of risk to contaminants in situ, be it in a controlled environment such as landfills or containment cells, or in uncontrolled environments in the soil. Decisions made during the engineering of contaminant containment facilities, and about whether a contaminant is 'safe' or not, must now be climate adaptive.

In addition, geochemical and hydraulic regimes within the broader contaminated land decision process must now allow for climate change. The practice of predicting the impacts from current knowledge must be extended to predictive measures, which take into account climate change.

The impacts of climate change on the assessment and management of contaminated land, not only in coastal regions but Australia-wide, have been discussed in this paper. The conclusions drawn are that awareness of the impacts of climate change in the science and decision-making process is only just emerging, and that this industry is a long way from implementing adaptive measures in mainstream assessment and management of contaminated land. However, recognition of the need for adaptive measures is the first step toward more adaptive practices in the assessment and management of contaminated land.

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