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There is a pressing need for municipalities and regions to create urban form suited to current as well as future climates, but adaptation planning uptake has been slow. This is particularly unfortunate because patterns of urban form interact with climate change in ways that can reduce, or intensify, the impact of overall global change. Uncertainty regarding the timing and magnitude of climate change is a significant barrier to implementing adaptation planning. Focusing on implementation of adaptation and phasing of policy reduces this barrier. It removes time as a decision marker, instead arguing for an initial comprehensive plan to prevent maladaptive policy choices, implemented incrementally after testing the micro-climate outcomes of previous interventions. Policies begin with no-regrets decisions that reduce the long-term need for more intensive adaptive actions and generate immediate policy benefits, while gradually enabling transformative infrastructure and design responses to increased climate impacts. Global and local indicators assume a larger role in the process, to evaluate when tipping points are in sight. We use case studies from two exemplary municipal plans to demonstrate this method's usefulness. While framed for urban planning, the approach is applicable to natural resource managers and others who must plan with uncertainty.

Keywords: urban planning; adaptation; land use; resiliency theory; uncertainty

1. Introduction

Adapting cities to climate change is a pressing issue. Creating a feasible adaptation planning process is difficult given the uncertainties inherent in the physical manifestations of climate change, as well as modelling uncertainty in the timing and magnitude of the change. The result is that it is easier for policy makers to ignore climate change in their policy making than risk being wrong, creating a significant barrier to the implementation of climate adaptive actions (Dessai and Hulme 2007; Carter 2011). While reducing the *underlying* uncertainty will only occur through improvements to climate science and modelling, reducing the *impact* of uncertainty can occur through improved policy and planning processes.

Significant research attention has been paid to using scenario planning and vulnerability assessments to improve policy and reduce uncertainty. However, the implementation stage of adaptation planning provides additional opportunities to reduce

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the impact of uncertainty. For planning purposes, what matters is the pace of change over the timeframe of the planning period, rather than some eventual end-point. However, the pace of local experience of climate change is difficult to project. As a result, municipal planning requires a highly flexible process that is designed to build incrementally towards transformational policies, if conditions prove necessary.

In this paper we synthesise existing research and emerging practice to conceptualise the 'windows of opportunity' planning model. This model brings together adaptation tipping points, incremental-to-transformational change, indicators and phasing. The model focuses on how to phase in the implementation of adaptation over time to allow flexible responses to the pace of climate change and the effectiveness of interventions already undertaken, in a way that engages both scientific and local knowledge.

Overall, this approach has several advantages. Perhaps most important, planned phasing matches investment to the stage of climate change that the community is experiencing. At the same time, it allows for incremental actions to build towards transformative change, while still benefiting from the advantages of a comprehensive process. This adaptive approach allows for testing of the efficacy of adaptive responses already undertaken. *In situ* monitoring of early and no-regrets policies will help determine how effective they have been in reducing locally-experienced impacts of climate change, and thus inform the need for future action. Challenges remain – large infrastructural investments or abrupt climate changes may require large, one-time responses. However, for the more gradual impacts of climate change, such as increased excessive heat days, more erratic and larger storm events, and extended drought and desertification, the model may be helpful in providing a road map to move forward with adaptation regardless of the level of uncertainty. We use case studies of two cities that are engaged in adaptation planning programmes similar to our model, to explore implementation.

2. Climate uncertainty and urban planning policy

The level of climate change that is already underway is startling (Kintisch 2009; Rahmstorf *et al.* 2007), and fairly consistently 'ahead of schedule' (McKibben 2011). In terms of mitigation, the hard fact is that global greenhouse emissions, far from declining, are still increasing. In 2010, the annual rate of emissions growth was 2.35%, higher than any of the previous five years (NOAA Earth System Research Laboratory 2011). Emission levels are generally following the 'high emissions scenario' projected as a worst case by the IPCC in 2007 (European Environment Agency 2011), and there is no apparent movement towards global governance systems that would lead to significant reductions (Stafford Smith *et al.* 2011). Recent findings that incorporate the growth of emissions since 2007 suggest that the globe is currently headed towards 4°C (7.2°F) of global average climate change, even if emissions reductions begin soon, and impacts will be worse in northern regions (Joshi *et al.* 2011).

2.1. Climate change timing uncertainty

Research suggests that among the range of barriers to implementing adaptation policy, uncertainty over the level of change is a key reason for difficulties in getting policy makers to take action on climate change (Bedsworth and Hanak 2010; Moser and Ekstrom 2010). From a policy perspective, climate uncertainty can be characterised as a function of magnitude, direction and timing of change (Joshi *et al.* 2011). However, given an average 20-year urban planning horizon, the pace and timing of change may be

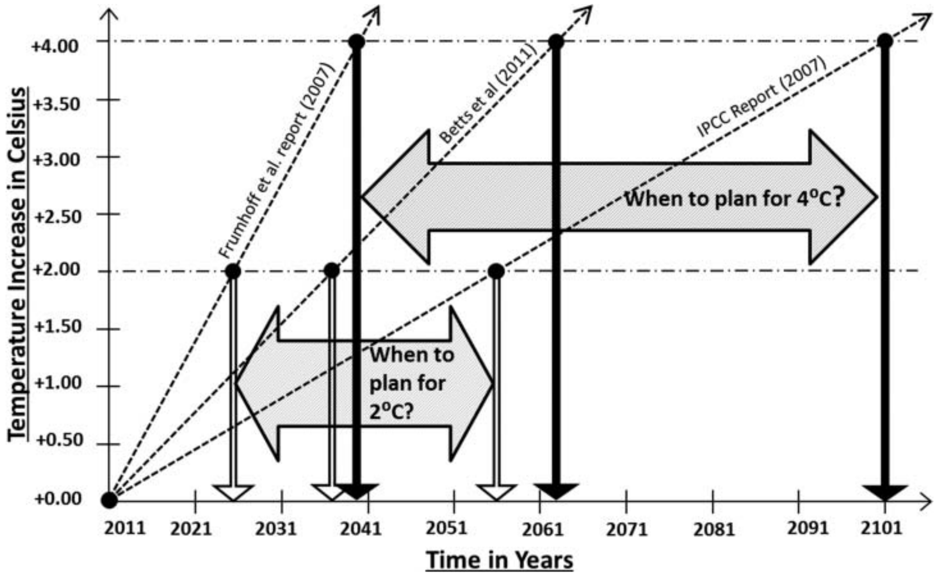

Figure 1. Timing of regional and global climate change impacts under high-emissions scenarios.

an even larger issue than where global climate change eventually occurs (Figure 1). As Figure 1 demonstrates, a 25-year plan (which is, admittedly, somewhat longer than most current policy horizons) could use a 1.2°, a 2.2°, or a 4.0° projection depending on the choice of global or regional forecast, and the longer the time horizon, the greater the uncertainty. These are not worst-case projections – none assume any 'abrupt' climate shifts (Alley *et al.* 2003).

2.2. Climate variability and climate change

Within the one to two decade time-frame that most plans work, the locally-experienced impacts of climate change are likely to be relatively small compared to the impacts of natural climate variability (IPCC 2012). Particularly at the local level it may be easier for communities to unite in addressing existing climate variability than in addressing a threat such as climate change that is less directly experienced, and more politically charged. As a result, simultaneously addressing current climate variability and climate change may in many cases be a more policy-beneficial approach than focusing on one or the other. In view of this, we sought to identify an approach that did not explicitly require the separation of natural and anthropogenic-caused climate problems, and instead focused on identifying a pathway that could assist communities in overcoming planning barriers while still allowing for short and long-term climate-change informed planning.

2.3. Uncertainty in impacts at the urban micro-climate scale

At the urban level, the impact of climate events can be magnified (or reduced) by the form and/or design of on-going urbanisation processes (Hardoy and Pandiella 2009; Schipper and Burton 2009; IPCC 2012), which create micro-climates that influence human climate-experience and ecological functions. One key variable is the amount of impervious surface. Higher imperviousness tends to lead to more flooding, more intense urban heat island effects, and increased desertification (Arnold and Gibbons 1996; Brabec 2009; Rosenberg *et al.* 2010; Stedinger and Griffis 2011). These affect an environmental cycle that results in higher levels of particulates in the air, increased levels of pollutants, particularly ozone, decreases in floral and faunal diversity and numbers, and increasing destabilisation of soils and floodplain systems (Stone 2012). In turn, these result in a higher incidence of human health problems (Few 2007; Shea *et al.* 2008), property damage and loss, and ecological degradation and species extinction (Nitschke and Innes 2008). The poor tend to be disproportionately affected by these changes as economic forces push them into areas that are highly impervious and flood prone with high heat indexes and unstable soils (UN-Habitat 2011).

Thus, if cities are built without attention to the climate impacts of development and the poor continue to be pushed into high risk areas, vulnerability to climate variability increases regardless of climate change, and is magnified with it (UN-Habitat 2011). A city designed with adequate green infrastructure to reduce urban heat island effects, with on-site stormwater management accompanied by effective watershed management systems, and with climate-adapted buildings built on stable soils, is better positioned to manage climate variability. These types of policies, which provide sustainable environmental and social benefits, are widely held to be the place to start for reasons both obvious and subtle. The obvious benefit is that they create better places to live without even having to argue the climate question (Heltberg, Siegel, and Jorgensen 2009). The less obvious reason is that their micro-climate impacts may slow the need to undertake expensive larger-scale interventions (Stone 2012). For example, good design can mean that a global climate temperature increase of 2°C may be locally experienced as the equivalent of 1°C.

2.4. *The challenge of uncertainty for municipal planning*

Taken together, these factors make clear that uncertainty in the timing and local impacts of climate change are a real and significant challenge to the municipal climate adaptation process. The most common municipal and research response is to focus on climate scenarios, often using two – a high and low change – assuming a relatively straight line pace of change towards the projected degree (e.g. 2°C or 4°C) at the end of the planning window. This is clearly better than assuming climate stability, but does not fundamentally address the problem of timing, and the implications above, that climate change seems to be consistently ahead of schedule.

3. Municipal adaptation planning processes

Cities across the globe are addressing these issues through preparation of climate adaptation plans, as well as through 'mainstreaming' of policy wherein climate projections influence infrastructure calculations and the like directly, without any specific plan in place. Underlying the various approaches cities are taking are certain theoretical models for how planning should be done. The current best-practices approach to adaptation planning follows closely from traditional comprehensive planning, but adds more focus on risk assessment, as shown in Figure 2.

To appropriately phase adaptation policies in ways that address current climate variability as well as on-going climate change requires implementation processes that bring together the advantages of these three planning approaches: the big-picture view of

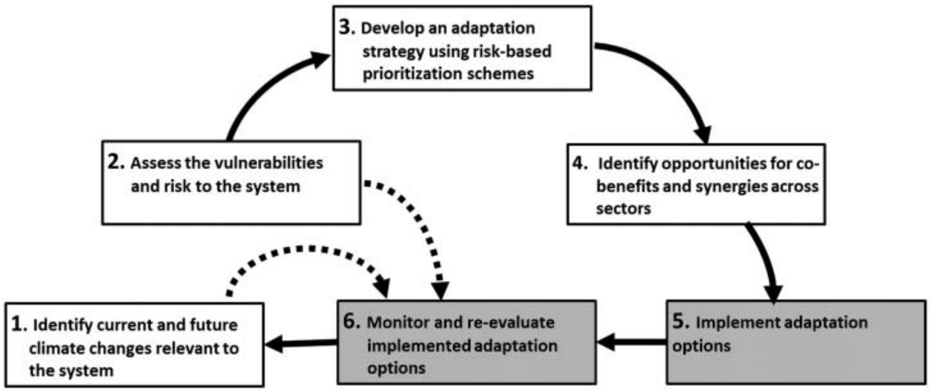

Figure 2. The Adaptation Planning process as recommended by the US National Research Council (2010).

traditional comprehensive planning, the specific goals and policy steps of incrementalism, and the continual testing and utility of adaptive management. One attempt to resolve these conflicts and achieve the best of each is seen in the recent guidance from the State of California to its cities and towns on adaptation, as shown in Figure 3.

The process of planning, even with the uncertainty of climate change, is fairly well understood because these models follow closely from the highly-developed practices of comprehensive planning. However, in a typical stable climate, the monitoring and phasing is not as essential as in a climate-variable environment. As a result, our model particularly addresses this post-plan, implementation phase, where there is significant opportunity to improve practices.

3.1. Maladaptation in the planning process

Along with more opportunity for public engagement, one of the advantages of a comprehensive process is that it allows for testing for maladaptation – defined by Barnett and O'Neill (2010, 211) as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups." They identified five distinct types of maladaptation: actions that "increase emissions of greenhouse gases, disproportionately burden the most vulnerable, have high opportunity costs, reduce incentives to adapt, and set paths that limit the choices available to future generations."

The first type of maladaptation listed above, where adaptive actions actually increase the use of fossil fuels, is a particular issue in developed countries and needs to be carefully managed (Howard 2009). A common example is residential air conditioning – it reduces the individual health impacts of heat waves, but at a long-term and shared cost of higher emissions. A particular challenge in phasing adaptation is the last issue in this set: remedies appropriate to 2°C may interfere with 4°C adaptations – for example, investing in sea walls to address sea level rise appropriate to a 2°C global temperature rise may make it more difficult to persuade homeowners of the need for planned retreat of their built structures on the lot or indeed off the coast altogether as change moves towards the sea level rise associated with a 4°C rise in temperature. In all of these cases, a comprehensive, thoughtful approach will assist in avoiding maladaptation, but the time

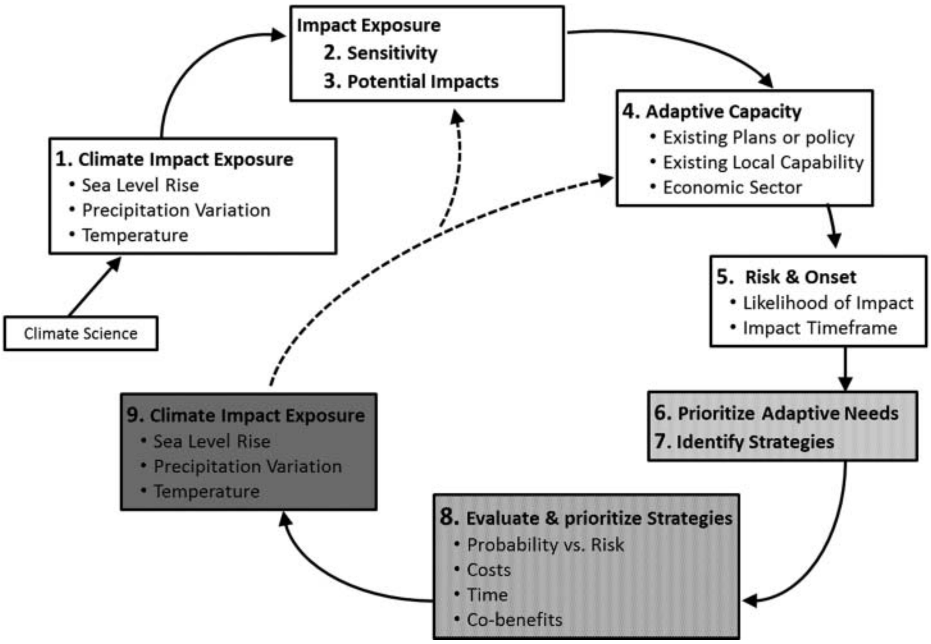

Figure 3. Local adaptation planning process advised in the (State of) California Adaptation Planning Guide (California Emergency Management Agency (Cal EMA) and California Natural Resources Agency 2012, 24 and Boswell *et al.* 2012).

and resources necessary to create a plan mean that it will probably be rarely updated. This is a particular problem for climate change and its uncertainties.

3.2. *Mainstreaming and incremental change*

Mainstreaming, which tends to focus on incremental change, proposes that small steps be taken towards very specific policy goals, with little effort towards a fully comprehensive approach (Lindblom 1959). Adaptive management builds on incrementalism by focusing on the need for consistent testing, monitoring and revision of policy as new information becomes available (Nelson, Adger, and Brown 2007; Jacobson *et al.* 2009).

While perhaps more discussed than actually practised, resilience theory demonstrates that rather than the unexpected, change is to be anticipated and tends to occur when thresholds are passed. As a result, planning needs to prepare social and ecological systems so that when stresses occur, systems can reorganise in a beneficial way to achieve a new and desirable system state (Folke 2006; Walker and Salt 2006). This focus on small steps and the underlying processes brings significant advantages to the planning process, but may come at the cost of long-term vision and policy coherence.

4. Windows of opportunity model

The ‘windows of opportunity’ climate change model we propose is based on the phasing of policy adoption and implementation to match new conditions. The model is illustrated in Figure 4, and its elements are discussed in the sections below.

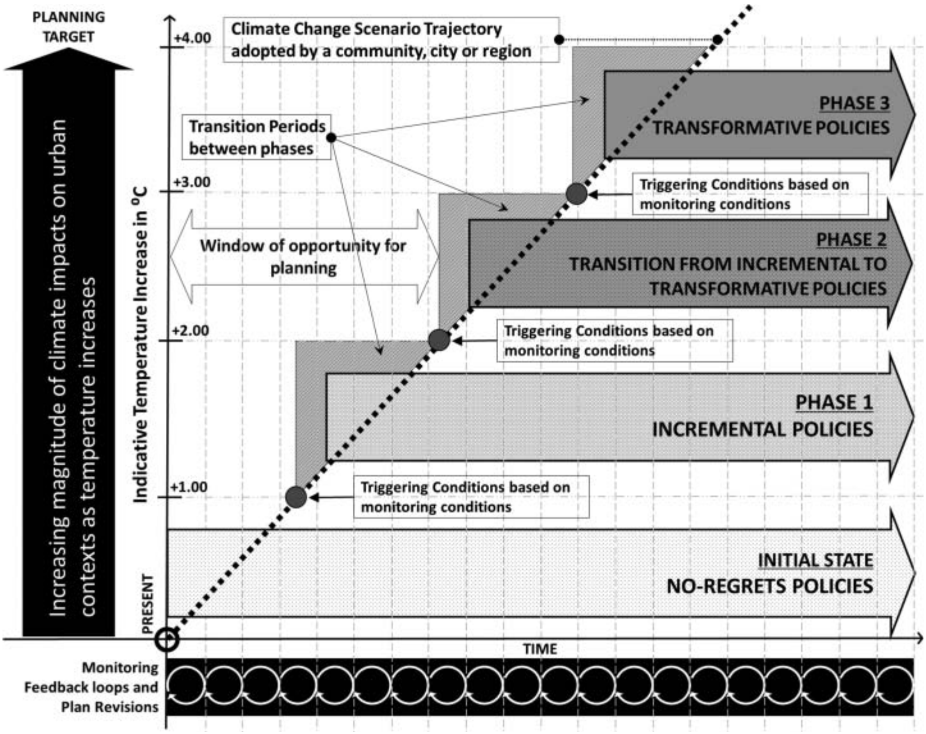

Figure 4. 'Windows of opportunity' climate adaptation model is based on phasing of policy to match new conditions.

Commonly, comprehensive plans are deeply tied to time, with specific roll-out dates for actions. In a linear, predictable process this makes perfect sense. Under climate change's conditions of timing uncertainty, it is much less effective. Because of this, a revised planning approach will focus on testing the actual environment and matching that to investments, rather than planning roll-out of policy based on specific years into the future. To achieve this, plans should identify incremental policies that can roll-out as needed, and that may cumulatively create a transformed state (Pittock, Jones, and Mitchell 2001; Wilson 2009). Following Park *et al.* (2012), transformation is defined as policies "that fundamentally (but not necessarily irreversibly) results in change in the biophysical, social, or economic components of a system from one form, function or location (state) to another" while incremental actions seek to maintain the essence and integrity of an incumbent system (Park *et al.* 2012, 119; O'Brien *et al.* 2012). In seeking to appropriately phase adaptation policies in ways that address current climate variability as well as on-going climate change, our model proposes a process that brings together the advantages of these three planning approaches: the big-picture view of traditional comprehensive planning, the specific goals and policy steps of incrementalism, and the continual testing and utility of adaptive management.

4.1. Phasing policies

The initial steps the community is likely to take are the no-regrets policies that many authorities have identified as the appropriate place to start. The IPCC defines these as "policies that would generate net social and/or economic benefits irrespective of whether or not anthropogenic climate change occurs" (IPCC 2007, 878; see also Callaway and Hellmuth 2007; Heltberg, Siegel, and Jorgensen 2009; Lempert and Collins 2007). One of the key benefits of no-regrets policies in urban environments is that they may, as noted above, reduce or delay the need to move to the next phase of the plan, with more intensive response. At some point, however, movement to a more intense policy phase is likely to be needed. In our model and increasingly in other studies, phasing is based on thresholds (Walker and Salt 2006), or what Kwadijk *et al.* (2010) have called Adaptation Tipping Points (ATPs) – moments in time where the magnitude of climate change is such that the current management strategies are no longer meeting local objectives, and new strategies need to be put into place. ATPs are recognised through the use of indicators, defined as statistical evaluative rubrics that reflect the status of a more complex system (Kates, Travis, and Wilbanks 2012), or at the local level as proxies for the status of the system.

4.2. ATPs and types of indicators

The ATPs are representations of local conditions and values and climate as experienced through the lens of local human-ecological systems interactions. As a result, determination of what will constitute an ATP needs to engage a participatory, bottom-up perspective as well as utilising existing sets of expert-derived indicators, and include natural and social/experiential indicators. Because of the difficulty of separating climate 'noise' from 'signal', scalar considerations (local versus regional) and the complex politics of decision making, using a suite of indicators in concert with local values will be more effective than any attempt to identify one threshold measure that indicates the need to move to the next phase. The indicators may be categorised into three types: climate related, social and local urban environmental indicators. A portfolio of indicators can include those that are scientifically robust, and those that are more locally meaningful even if less scientifically robust (Boulanger 2008; Feiden and Hamin 2011).

Officially approved national/supra-national level climate-related indicators are beginning to be easily available. In the US, for example, NOAA has developed Global Climate Change Indicators[1] while the US Global Change Research Program prepares a national climate assessment and is developing a rigorous set of indicators including societal data.[2] The Annual Greenhouse Gas Index prepared by NOAA provides a simple number of cumulative global emissions (US EPA 2010). Europe has developed indicators for widespread use, especially the 2008 indicators report for climate impacts (European Environment Agency, World Health Organization, and JRC European Commission 2008), the 2012 environmental indicators report for greenhouse emissions and environmental conditions (European Environment Agency 2012), and the on-going data sets available on the EEA website. Data for developing countries is available through the World Bank Climate Change Knowledge Portal,[3] although with less detail than the US or European initiatives.

However, global level indicators cannot take account of the local effects of micro-climate, the positive outcomes of policy already implemented or the changes in context that occur outside the plan, such as new up-shore developments. As a result, locally derived and relevant indicators are an important part of the process. Local indicators provide the opportunity to engage community members, perhaps the climate planning steering committee or other local board, as well as local staff in both defining what is meaningful in the particular context of that plan, and in regularly measuring and reviewing outcomes. While the more scientific indicators provide validity, locally meaningful indicators assist in developing community support for and understanding of the need for the policy change (Gasteyer and Flora 2000), and respond to the IPCC's 2012 call for more direct inclusion of local knowledge in planning. Examples of local environmental indicators might include five-year moving averages of the number of extreme heat days in the region; number of bank-full and/or flood stage days; the increase in level of mean high tide; levels of base flow in area rivers as an indicator of drought; miles of beach impacted by storms; the number of individuals hospitalised for heat stress or asthma; or similar indicators. The number of times a sea wall is overtopped per year, for example, may be a locally-meaningful indicator that encourages action – but for that to happen, the record of occurrences must be made and annually reviewed. By focusing on local impacts (e.g. heat waves experienced) rather than only the causes (globally higher GhG) these types of indicators help to overcome the uncertainty of micro-climate effects, timing, and unanticipated conditions.

A key role of these indicators is to create prior agreement, or at least the opportunity for regular discussion, on what would constitute an ATP for the local community. Local values will determine whether they can tolerate three days when roads are flooded per year, or perhaps five? One event per year with more than 10 residents hospitalised due to heat stroke? These are not likely to be easy decisions, and require the community to engage very directly with decisions on acceptable levels of loss and risk management. This also allows better integration of local knowledge systems into formal institutions.

4.3. Example: London and the Thames Barrier

London's plan for the Thames barrier provides a recent example of combining phasing, indicators and ATPs. By maintaining a 1000-year flood standard, using the dual indicators of freeboard and storm surge, and incorporating various levels of projected sea level rise, the city of London identified the tipping points for increasing the height of the Thames Barrier (see Figure 5). While this is an analogous application of the theoretical basis of our model, the model goes beyond this application to include multiple adaptation strategies, and includes value-based as well as quantitative measures.

5. Application in case study communities

The application of the proposed model is illustrated and grounded through two case study examples. The examples were selected from a larger pool of climate adaptation plans listed in available databases.[4] Comprehensive adaptation plans were selected that explicitly recognised the uncertainty of magnitude and timing of climate change impacts and went beyond assessment to implementation, regardless of geographic or scalar considerations. We then chose case studies that included as many components of the implementation model as possible, including: a form of phasing or gradual implementation of adaptation policies and measures; triggering conditions or threshold indicators; monitoring periods; and the provision of time periods and transitions for plan update based on hard evidence that we term 'windows of opportunity' for planning implementation. In both case studies, analysis was carried out to extract the components based on the criteria presented in Table 1.

Two approaches were used to define the model components. A descriptive approach was utilised when the details existed in the plan allowing minimal processing of information. A prescriptive approach was used when details were lacking and required

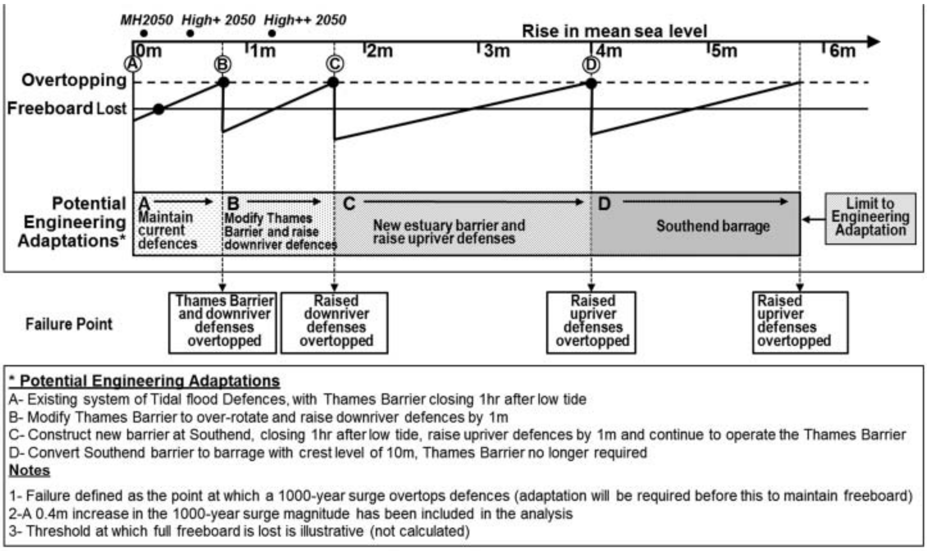

Figure 5. An example of phased engineering adaptation for the Thames Barrier, responding to potential climate change trigger points (Redrawn from Reeder *et al*. 2009, 62).

Table 1. Components of the implementation model used to assess case study examples. Component details indicate the analysis conducted by the authors to identify and make explicit these components.

Components	Component details
Gradient of policy measures (phasing)	Adaptation measures included in plans are assessed and organised into a continuum of policies, from “no-regrets” to transformational.
Windows of opportunity and transition periods	Initial period or period between phases allocated for extensive revisions and update of implementation based on the shorter periods of monitoring feedback loops. Actions to be conducted by the planning team are identified and included.
Triggering conditions	Are derived from the critical community paths and are threshold indicators of impacts specific to the plan context. These triggers along with cost-benefit analysis instigate the move from one phase of policies to the other.
Monitoring feedback loops	Time allocated to monitor implementation measures, monitor triggering conditions, incorporate technological advances and review of, or parts of, the plans. Monitoring periods are indicated in plans and accordingly included in the model application.
Risk assessment: Cost Benefit analysis	While not included in the model application diagrams, cost-benefit analysis is discussed in each case to show the primary focus of the magnitude of risk as well as an indicator (with triggering conditions) to move through policy phasing.

additional processing and analysis. In each case study relevant components were identified, simplified and then mapped against the community critical path. Adaptation measures were reorganised to fit the continuum of measures with specific attention given to ensure that later measures were built onto previous ones and supported future conditions, while maintaining the objectives of the plan. Where measures were missing, the authors proposed complimentary measures (indicated accordingly).

The selected plans are unusual and particularly useful when presented according to the implementation model, because they specifically focus on implementation of adaptation by considering triggers for movement to the next stage of their adaptation plan. Thus they provide examples of policy phasing that may reduce (while not necessarily eliminating) the extent of uncertainty in the decision-making process.

5.1. Managing rising sea level impacts: the City of Clarence, Tasmania, Australia

The Clarence City adaptation plan for coastal areas (Clarence City Council 2009) provides a road map for adaptation for risk prone areas within the city boundaries. The plan develops solutions that support the continued use of coastal areas while recognising the need for long-term protection, accommodation and retreat as sea levels rise (SLR). "While use may be practical and desirable for many years, there will come a trigger when a response will be required to manage increasing risk" (Clarence City Council 2009, iv). In Clarence's case, the triggering event, or ATP in our terminology, is a specific level or levels of locally-experienced sea level rise. The planning is based on a community accepted worst-case scenario (critical path) of future conditions, but emphasises "encouraging performance based responses that maintain acceptable levels of risk" (Clarence City Council 2009, v). The plan demonstrates that managing risk today through adaptation measures can reduce impacts from sea level rise "from a factor of 10 up to a factor of 100, and economic costs of adaptation would be minor compared to the damage avoided" (Clarence City Council 2009, iii).

Community participation and ratification is significant in the decision-making process in spite of the challenges this poses to decision makers. Interactive strategies that are participatory and combine bottom-up and top-down approaches enhance a "community's ability to cope and maximize community support for policy measures, especially in the case of drastic measures" (Clarence City Council 2009, v). The combination of these principles render the adaptation plan flexible and open for improvement and revisions as the effectiveness of interventions becomes clear and impacts of climate change increase.

The plan details include several components of the 'windows of opportunity' model. For this paper, we focus on one high risk zone – Lauderdale and Roche Beach – out of the 18 identified risk zones. Lauderdale is a 4300 m long low-lying sandy isthmus with dunes and housing development. The plan identifies three major hazards for this area: storm surge and erosion, inundation, and rising water tables leading to failing septic tanks. Complicating the situation are current coastal beach movement processes (not related to climate change),[5] which will occur at a faster pace under a changing climate condition.

The plan uses six primary and 13 secondary variables to identify the extent of exposure resulting in a risk priority ranking: areas currently at risk (next 25 years), areas at medium risk (25–75 years), and areas with longer term risk (beyond 75 years). Sea level rise (SLR)[6] scenarios are developed for the whole city based on IPCC (2007, 17) emission projections with mid and high values for three milestone years: present (zero SLR), 2050 (mid at 0.2 m and high at 0.3 m SLR), and 2100 (mid at 0.5 m and 0.9 m SLR). Triggering conditions or ATPs are estimated for each zone based on the indicators of the current 100-year Average Return Interval (100yr ARI) for erosion/recession of the coastline, wave run-up and inundation. ATPs will be triggered when the 100yr ARI would probably lead to significant damage to property or where more extreme events would make emergency responses difficult. Identifying when an ATP is likely to occur, or is reached, is dependent on continuous monitoring of selected indicators, climate science developments, advancements of technology and community perception of risk. The critical path and ATPs were deemed realistic and probable by experts working on the plan and ratified by the community.

The first ‘window of opportunity’ is used to refine the plan by conducting detailed studies of all risk zones, secure immediate and long-term funding, undertake cost-benefit assessments of measures, and update climate information and indicators. Phases after implementation are the next ‘windows of opportunity’, in which the outcomes of policy interventions on micro-climates can be evaluated and the plan can be revised. Future plan revisions depend on ongoing monitoring of the selected indicators, implemented measures, lessons learned and evaluation of the ATPs. A five-year period is suggested in the plan as a review period or the monitoring feedback loop in the model. The plan explicitly recognises the need for evidence-based monitoring by observation and ground measurement to understand the actual path of the indicators in relation to a changing climate. The provision of initial, transition and monitoring time periods allow for the continuous updating of adaptation measures to respond to actual changes.

The adaptation measures address protection of dwellings and infrastructure, accommodate the changing coastline, and ultimately recommend retreat if ATPs indicate the necessity. The full set of measures included in the plan is clear enough to be reorganised into the continuum of measures in our model with no additional processing required. These are included in the model application (Figure 6), providing a continuous approach where implemented measures support future policies. An example for the protection of existing properties is increasing the height and vegetation of existing sand dunes as no-regrets measures that could transition into the construction of a sea wall, phased in based on ATPs. At present, using the indicator of wave run-up, the current level for a 100yr ARI is 2.8 m and dune average height (where present) is 3.5 m. Minor sand nourishment to fill gaps and vegetation for stabilisation will provide immediate protection. When the ATP for wave run-up of between 2.8 m to 3.2 m is reached, additional height will be added (approximately 1–2 m) to ensure protection. When the ATP of 3.7 m is reached, topping existing dune height, then additional height of another 1–2 m may be required. If monitoring of the indicator shows that the future trajectory seems to be exceeding set thresholds, then an ATP has been reached, and transitioning to sea walls is triggered.

The plan provides a cost metric that is also used as an ATP, based on the cost of adaptation measures per protected dwelling. As long as the cost of measure per dwelling remains lower than the value of the property, the next phase of adaptation is deemed feasible. While the plan explicitly states this principle, there is no provision of an average property value to assess and include in the model diagram. The example in Table 2 may demonstrate the utility of the cost metric.

The cost of sand nourishment at present conditions for a 100yr ARI is $136,000 per property for 19 protected properties. With an SLR of 0.3 and protecting 108 properties with sand nourishment, the cost is $71,000 per property; for a 0.9 SLR and 195 protected properties, the cost increases to $119,000 per property. When compared to the cost of a sea wall for the same number of protected dwellings, at present SLR 100yr ARI, the cost per dwelling is $974,000 and for an SLR of 0.9 (worst case scenario) is $174,000.

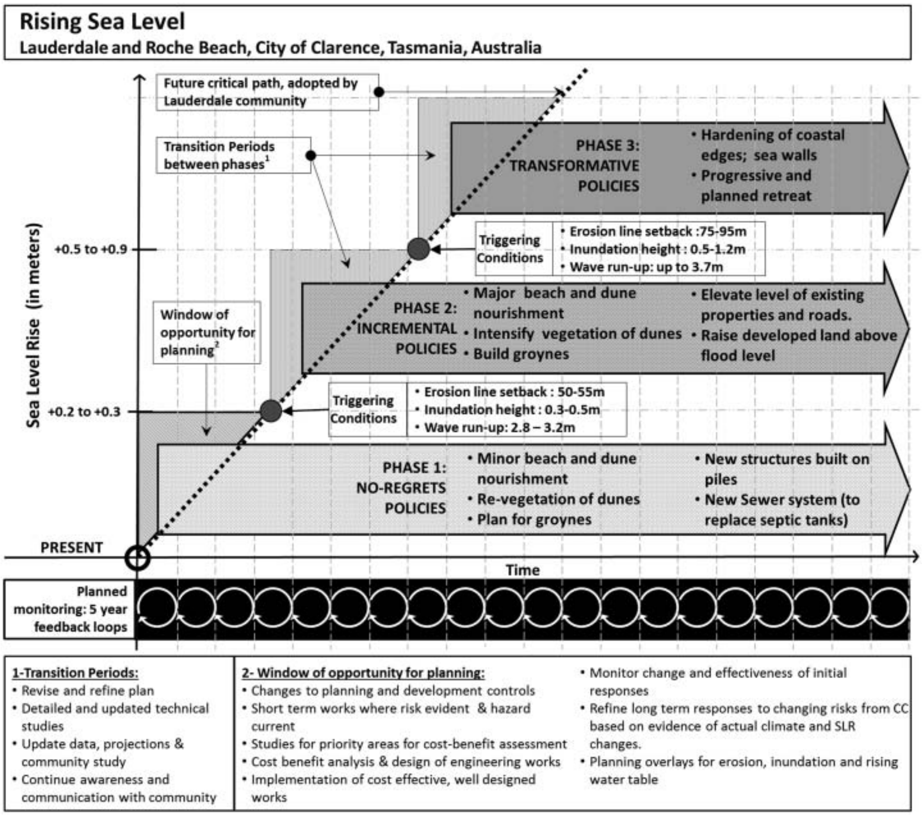

Figure 6. Phasing model for Lauderdale Area, City of Clarence, Australia.

This cost metric is also used to reduce the extent of exposure to risk. Prior to the 25 year cut-off period, it is assumed that owners have located within these this risk area prone without knowledge of the associated future risks. After 25 years, and with awareness and communication campaigns set by the plan, residents will be assumed to have made a conscious choice to locate in a risk-prone area. At that time more costs will be allocated to individual properties. This should reduce the number of structures exposed to risk and thus future public costs for adaptation.

Using our model, we organise the gradient of responses identified for Lauderdale along no-regrets to transformative measure gradient in Figure 6. The no-regrets

Table 2. Cost comparison illustration to aid decision making for plan implementation (adapted from Clarence City Council 2009).

Adaptation measure	Adaptation tipping point	Total cost of measure	No. of properties in zone	Cost per property
Sand Nourishment	100yr ARI	$2,584,000	19	$136,000
	SLR 0.03 m	$7,668,000	108	$71,000
	SLR 0.09 m	$23,205,000	195	$119,000
Sea Wall	100yr ARI	$18,506,000	19	$974,000
	SLR 0.03 m	–	108	–
	SLR 0.09 m	$33,930,000	195	$174,000

responses are critical for implementation as soon as possible, and as the plan notes will provide protection and maintain the coastline as an amenity. As monitoring of the indicators demonstrates changes in conditions, more intense, transformational measures such as sea walls and planned retreat kick in, assuring adequate responses. Mapping out the likely policies and the conditions indicating their need means that maladaptation is less likely, and costs can be better managed over time.

5.2. Managing flood impacts from extreme precipitation events: the City of Copenhagen, Denmark

The Copenhagen Adaptation Plan is a state-of-the art document, developed in 2011 to address an array of climate change impacts with a particular focus on extreme precipitation events and rising sea level. Such extreme conditions are already occurring in Copenhagen. The cloudburst event of July 2011 poured down 150 mm of rain within two hours, a city record since measurements began in the mid-1800s. The result caused estimated insurance damage of €650–700 million ($US 820–880 million) (EEA 2012). This focusing event helped the City of Copenhagen to expedite research and development of the comprehensive adaptation plan in a way that allows gradual and flexible adaptation over time (City of Copenhagen 2011).

The plan presents many exemplary practices, but for our purposes its main interest is its principle that adaptation should be flexible and staged. The plan is developed for incremental implementation with continuous monitoring and updating to include advancements in climate science, scenario projection methodologies and climatically responsive planning. The prioritisation, implementation and extent of effectiveness of adaptation measures are categorised based on three levels of intensity: level 1, to reduce the likelihood of occurrence of an extreme event; level 2, to reduce the scale of impact; and level 3, to reduce the extent of vulnerability. The choice of the appropriate level is based on the feasibility of implementation within a specific zone of Copenhagen. For example, if the reduction of likelihood of an event (level 1) is not feasible within a zone, then reducing the scale of impact (level 2) to manage damage is prioritised. If that is not deemed feasible, then reduction of vulnerability (level 3) becomes the dominant action. In addition to the intensity of measures, the choice of action will also depend on the geographic scale where the action is being implemented. Table 3 shows the relationship of the three levels of measures and the five geographic scales of planning relevant to Copenhagen: the region, the municipality, the district, the street and the building. This approach ensures coordination and integration across planning scales and measure intensities, thereby better avoiding maladaptation and unnecessary investments.

To apply the ‘windows of opportunity’ model (Figure 7), several steps were required to process the data available in the plan. The extensive measures shown in Table 3 were re-categorised into three main column headings representing the three intensity levels with corresponding continuum of four types of adaptation measures: (1) reduction of quantities of flood water going into the sewer system (disconnection of stormwater from combined sewer system, detention/retention basins, roofs of buildings for water collection, SUDS, etc.); (2) conveyance of flood water (redesign sewer system, pumping water to sea, etc.); (3) protection of infrastructure and assets (raising levels, moving sensitive facilities, building dikes; and (4) general emergency preparedness such as sand bags, ‘Plan B’, backwater valves, etc.). The set of measures runs parallel to ensure adequate climate proofing of Copenhagen.

Table 3. Example of integrating adaptation measures across geographic scale and reduction of risk for flooding from extreme rain events and rising sea level (adapted from City of Copenhagen 2011, 27 and 35).

Geography/measure	Level 1: Reduce likelihood	Level 2: Reduce scale	Level 3: Reduce vulnerability
Region	•Delay quantities of rain in catchment: Establishment of detention basins within catchment areas •Pumping excess run-off to sea	•Emergency preparedness and infrastructure protection •Protection of vulnerable infrastructure Metro, S-trains, tunnels, cultural assets •Establish warning system for high waters	•Protection of vulnerable infrastructure Metro, S-trains, tunnels, cultural assets
Municipality	•Disconnection of stormwater using SUDS* •Increased sewer capacity: New dimensional design based on future new capacities •Pumping of excess run-off to sea •Establishment of local dikes •Raise building elevations	•Disconnection of stormwater using SUDS •Planning**** •Warning systems	•Planning**** •Emergency Preparedness
District	•Establishment of dikes •Decoupling of rainwater using SUDS •'Plan B'** •Establishment of dikes • Raised building elevation/threshold***	•Decoupling of rainwater using SUDS. •Emergency management: sandbags etc.	•Moving of vulnerable functions and installations to safe places
Street	•Local management of storm water: 'Plan B' solutions, separation of stormwater from sewer •Raised building elevation/threshold	•Control of stormwater runoff: disconnection of stormwater using SUDS •Preparedness: sandbags etc., raised building elevation/threshold, sand bags	•Moving vulnerable functions and installations to safe places: moving electrical cabinets for light regulation, pumping stations etc. from low-lying points
Building	•Disconnection of stormwater from sewer •Backwater valve •Raised building elevation/threshold	•Backwater valves, sealed basements, preparedness, sandbags etc.	•Move vulnerable functions away from basement level (service rooms, electrical panels etc.)

Notes: *SUDS: Sustainable Urban Drainage Systems. "SUDS consist of a number of different elements, all of which serve the purpose of managing stormwater locally. These may be elements that delay/store the water, that treat the water either before discharge to bodies of surface water or percolation of the stormwater" (City of Copenhagen 2011, 26).
** 'Plan B' uses street surfaces as conveyance routes for excessive run-off.
*** Raised threshold: raising egress edges to prevent surface run-off water from entering building.
**** Planning measures include: (1) "New sewer systems already have to be dimensionally designed today so that they cope with the projected volumes of rain and consequently meet the service objective. The dimensional design base has to be incorporated into all relevant municipal plans. (2) Separation of common sewer in SUDS solutions is to be promoted and implemented" (City of Copenhagen 2011, 27).

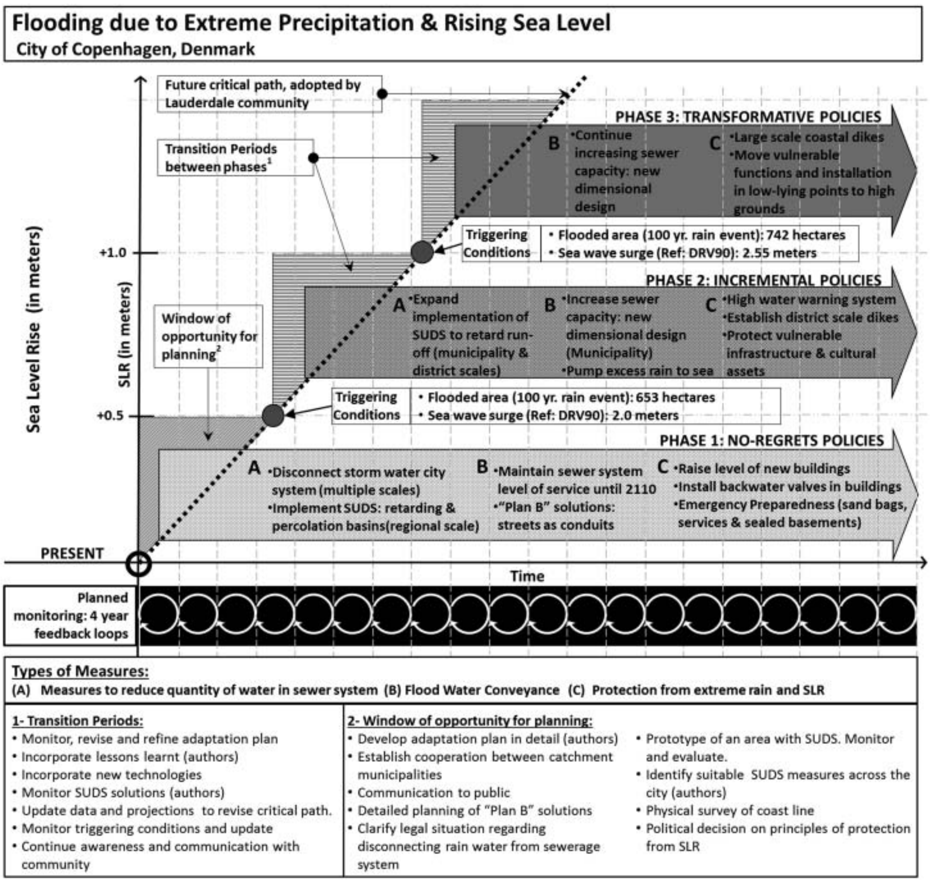

Figure 7. Phasing model applied to the Copenhagen Climate Adaptation Plan (2011).

Monitoring is planned for four-year periods. In addition to plan updates, technological advancements in climate science and monitoring of indicators and their ATPs, these 'windows of opportunity' provide the chance to address context specific considerations related to Copenhagen. For example, the urban watershed that Copenhagen rests within is under several administrative jurisdictions. Therefore, appropriate coordination and collaboration among these administrative entities is necessary to reduce the likelihood of extensive run-off from extreme climate events originating in these regional jurisdictions.

The plan's ATPs are based on indicators of total flooded area (from extreme precipitation and wave surge) and sea wave surge. Similar to the Clarence case study, a financial metric is used to evaluate every step of the adaptation implementation. The risk index is included in the model as an additional criterion to move up the ladder of adaptation measures. The risk index is calculated as the difference of the public cost of adaptation measures and the cost of potential risks based on a specific ATP condition.

5.3. Case discussion

The application of the model to these two exemplary cases demonstrates that planning for the implementation of adaptation measures is possible regardless of the uncertainty involved. While the plans vary in the areas addressed, context and methodology, both plans recognise the need to move ahead with adaptation because the costs of ignorance are too high. In the context of uncertainty of information about the future, flexibility in adjusting plans, measures and methodologies is core to climate proofing communities. Organising adaptation measures from no-regrets to transformational measures carries wide benefits in the current 'window of opportunity', and incrementally adds measures as needed using information, advance technology and monitoring of implemented projects to indicate when the next phase is required. To address the barrier of the high cost of adaptation, both cities anticipate moving gradually along a spectrum of integrated measures, allowing the opportunity to begin implementing while monitoring the need for next measures. Focusing on conditions rather than timeframes reduces the barrier of uncertainty when it comes to adaptation policies.

6. Concluding remarks

Urban areas need to build resilience to climate change and variability. Implicit in the approach presented in this paper is the subtle but radical suggestion that phasing of policy be linked to locally experienced outcomes, rather than a strongly pre-defined plan that rolls out over time. This allows a focus on the local experience of environmental change and the outcomes of interventions put into place. Allowing this flexibility reduces one barrier in policy implementation, as policy makers' fear of acting too precipitously is reduced. Action will only be taken when it is warranted – but plans are in place so that necessary action can be rapidly implemented.

Having a long-run view of an implementation path allows testing for maladaptation in proposed policies. Using a suite of indicators with pre-designated tipping points (ATPs) allows for the explicit inclusion of local knowledge, and reduces the need to differentiate between climate change and climate variability. Indicator sets need to be developed collaboratively amongst governmental levels, and in some instances be translated to common language such that communities can readily use them. National or state level agencies may wish to develop suggestions for local indicators to help jump-start community considerations. While we have used an urban planning framework, the basic approach of adaptive planning with pre-determined thresholds is also applicable to natural resource areas and conservation lands.

This analysis supports the literature's emerging consensus on the importance of starting with no-regrets policies (Biesbroek *et al.* 2010; Juhola, Peltonen, and Niemi 2012), many of which are well-established best urban planning practices anyway. These are the policies of sustainable social and environmental development, including strategies for increasing green infrastructure in urban systems, increasing public and non-motorised transportation and protecting ecosystems. In a given urban micro-environment, implementing these policies for cleaner, greener, healthier cities can slow the need for more radical transformations by directly addressing some of the impacts of climate change.

There is a great deal that is not addressed here. Perhaps the most pressing item is the difficulty of large dollar and long-timeframe investments, those that do not yield to gradual implementation. Permitting major water or shoreline interventions can take many years, and stormwater piping lasts decades; for these major, long-term investments, future-climate-adapted policy based upon realistic climate change projections is needed now. Other challenges come from the need to balance scientific rigour and local meaningfulness in monitoring and choices of indicators; identifying appropriate portfolios is essential. Significant issues revolve around communicating with the stakeholders and elected officials, accustoming them to working around uncertainty and time concepts suggested by this approach to the planning process. Continuing research on these issues is necessary.

Given the long time horizons of urban land use and infrastructure, it is essential that local officials begin including climate adaptation in their planning, but given the uncertainties inherent in climate projections, it is difficult for them to move forward. The strength of the approach presented in this paper is the ability to make incremental decisions about investments in climate change adaptations, but with a comprehensive view that minimises maladaptation. At this point in time, the imperative is to proceed, flexibly but thoughtfully.

Notes

1. See http://www.ncdc.noaa.gov/indicators/
2. See http://globalchange.gov/what-we-do/assessment
3. For Brazil, for example, see http://data.worldbank.org/country/brazil#cp_cc
4. Georgetown Climate Center clearing house, see http://www.georgetownclimate.org/adaptation/clearinghouse); ICLEI adaptation resources, see http://www.icleiusa.org/climate_and_energy/Climate_Adaptation_Guidance/free-climate-adaptation-resources?searchterm=climate+adaptation+plans; NOAA adaptation and action plans data base, see http://collaborate.csc.noaa.gov/climateadaptation/Lists/Resources/AdaptationAction%20Plans.aspx; and the United Nations Environment Programme (UNEP), climate change adaptation resources section, see http://unfccc.int/adaptation/workstreams/nairobi_work_programme/items/6547.php
5. The plan identified any combination of the following coastal processes not related to climate change: adjust to past sea level rise (post-ice age) or recent sea level rise, long shore drift, storm cut and rebuild, beach rotation, and changes in sea grass colonies that may trap or release sand (Clarence City Council 2009, 52).
6. SLR based on Australian Height Datum (AHD) in Tasmania is based on mean sea level for 1972 at the tide gauges at Hobart and Burnie which was assigned the value of zero on the AHD.

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