BUILDING OUR FUTURE

Human infrastructure both contributes to and is affected by global change. The engineering and climate research communities must work together to respond and adapt to such changes, say **Faisal Hossain** and **Julia Pongratz.**

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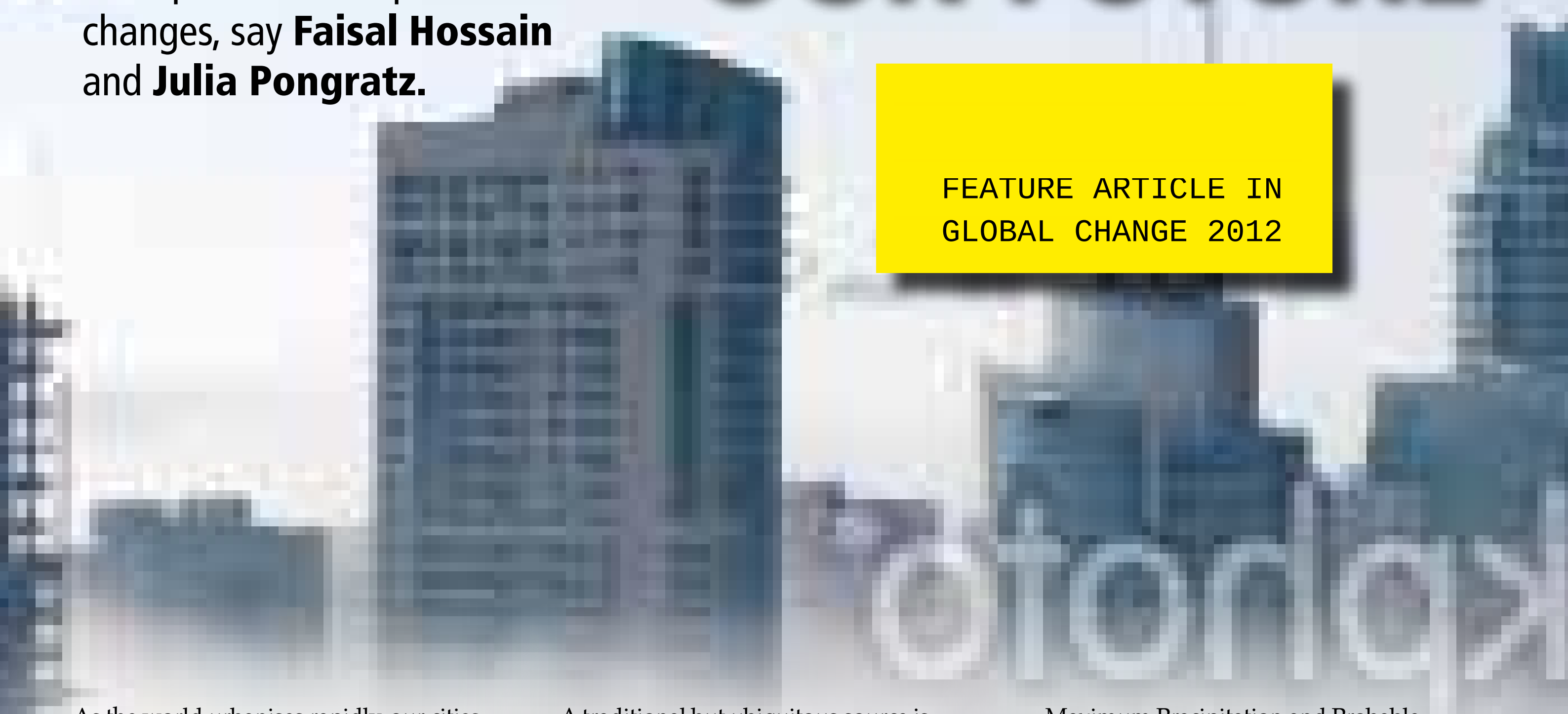

As the world urbanises rapidly, our cities are becoming larger (**see page x of this issue**): they are growing as fast as, or faster than, urban population. The modification of Earth's surface for urban living is irreversible on human timescales and affects the local and global climate and the environment. Previous work has shown that changes in land properties such as albedo, roughness and moisture content can significantly influence climate variability at the regional scale and also affect extreme events (for example, Seneviratne *et al*. 2006). Several initiatives are currently fine-tuning our understanding of the impact of land-cover change on climate, including the IGBP synthesis on land-use change and climate.

While providing fodder for global-change researchers these rapid changes – coupled with the possibility of increased climate variability and economic uncertainty – are creating new challenges for the infrastructure engineering community. Urban settlements have an insatiable appetite for energy and resources, a steady supply of which needs to be assured. Take water, for example.

A traditional but ubiquitous source is artificial reservoirs created by damming rivers upstream of cities. These large-scale infrastructures trap a sufficiently large amount of water from the local or regional water cycle to make up for a shortfall when demand exceeds the variable supply from nature. Although few new projects are being undertaken in the United States or Europe, large dams are being constructed and contemplated in several other nations to support agriculture as well as rapidly growing urban agglomerations. For example, the Southeast Anatolia Project in Turkey, the Three Gorges Dam in China and the proposed project to link Indian rivers.

The long-term planning of such infrastructure and the maintenance of existing infrastructure is complicated by the possibility of changing weather patterns during the coming century. But model results do not necessarily agree with each other and lack the resolution that would allow robust regional or local-scale projections. Climate models do not yet provide the kind of information needed by engineers and planners – for example, the Probable Maximum Precipitation and Probable Maximum Flood projected into the late 21st century – that would allow testing the future functional resilience of dam infrastructure.

Despite obvious links, collaborative studies involving the engineering and global-change research communities are not common, and there is little co-design of research. Clearly there is much scope for engagement between the two communities to understand change and develop resilience.

An opportunity for engagement

Climate change will put pressure on existing infrastructure and pose new challenges for the infrastructure being contemplated by shifting mean climate and increasing the frequency and intensity of extreme climate events. In many regions the water balance is altered by temperature and precipitation changes significantly beyond what had been anticipated when reservoirs were built. As return intervals of flooding increase, dam systems and wastewater infrastructure may exceed their capacities

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– for example, the Folsom Dam on the American River near Sacramento. Heat waves as the summer 2003 in Europe, which caused yield losses and ten thousands of deaths, are expected to become more frequent. Infrastructure will have to adjust to ensure sufficient resilience of energy generation and transmission, approaches to cool public facilities will need to be changed and urban green spaces will need to be increased to avert public health risks (IPCC 2011).

Of course, infrastructure itself contributes to land-use/land-cover change (Figure 1). We know well the first-order changes in atmospheric temperature (for example, urban heat islands) or humidity (for example, cooler environment near reservoirs or irrigated regions) caused by infrastructure. More recently, second-order impacts on climate have been identified. For example, the downtown high-rise regions of a city can split wind and create convergence downwind leading to lifting of air and higher precipitation under certain circumstances. Increased air pollution in cities can also affect the mechanisms leading to precipitation. Incidentally, some of these effects have been also known to overwhelm city sewer systems (Reynolds *et al*. 2008).

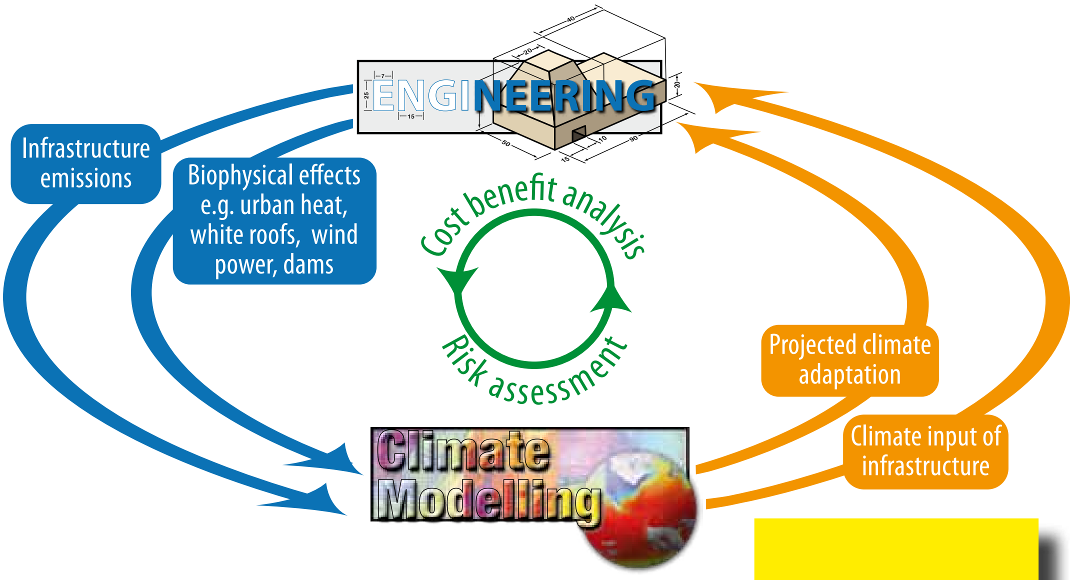
Global data and simulations by Biemans *et al.* (2011) suggest that the contribution of dams to irrigation has increased spectacularly from 5% (around 1900 A.D.) to almost 40% in the 21st century. Besides direct climate effects such as changed albedo, flood control or hydropower dams can trigger a faster pace of urbanisation of the downstream valley regions, whereas irrigation dams intensify agricultural production in the vicinity of the reservoir. In a study of about 100 large dams in the US, Degu and colleagues (2011) found that dams in the Mediterranean and arid climates exerted the greatest and most detectable mesoscale impact on temperature, humidity and other storm-forming properties, whereas humid regions were least affected.

This study underscores the need for a broader view of the change a dam can typically trigger during its lifespan, and has important implications for climate-change adaptation too. According to the most recent report card produced by the American Society of Civil Engineers (ASCE) in 2009, most types of infrastructure (dams, roads and urban drainage systems, for example) in the US and in most of the industrialised world currently average a grade of D minus (http://www.asce.org/reportcard). Out of five key solutions suggested by ASCE, one is to "Promote Sustainability and Resilience." In recent discussions on promoting resilience of our infrastructure, the issue of 'climate change' has featured prominently as a path forward for the 21st century in some countries such as the UK (www.defra.gov.uk/environment/climate/sectors/infrastructure-companies/).

The inclusion of climate in discussions of forging water infrastructure resilience is timely. However, the primary focus has so far been on adapting infrastructure in a top-down fashion to the changing extremes expected from climate model projections. This misses the possibility of interaction of local-to-regional climate effects of large infrastructure with global climate change. For example, a warmer atmosphere implies greater capacity for holding water vapour, which might amplify the local climate impact of infrastructure. There are important lessons to be learnt from the global-change research community studying land-use/land-cover change, which has demonstrated clearly the impacts of local changes on the climate at various scales.

At the same time, researchers studying climate impacts of land-use change are also beginning to recognise the need for better engagement with the infrastructure engineering community. A key field aims at understanding fundamental land-atmosphere processes and fingerprinting the direct human impact on climate. Urbanisation and other land-use change in the US and China led to an important component of the increase in mean temperatures and the decrease in diurnal temperature range observed over the last decades (e.g. Kalnay and Cai 2003). Earth system models are consequently increasingly extended to account for effects of infrastructure on climate: for example, some General Circulation Models can use detailed information on urban structure where this is available (Oleson *et al*. 2010). A wide field for close collaboration may open with the new generation of General Circulation Models that allow local grid refinement in global climate simulations. Regional climate models today already work on the level of watersheds and aim to predict local hydrological changes under given scenarios. Earth systems models will thus increasingly be able to make use of inputs about local and regional infrastructure, and may eventually allow quantification of infrastructural feedbacks on climate from the local to global scale.

Inputs from the engineering community are also needed to assess future intended and unintended consequences of human activity on climate. Scenarios of infrastructural change form part of the broader socioeconomic scenarios underlying all climate projections. As the CO_2-emitting infrastructure that determines future climate change is yet to be built (Davis *et al*. 2011), information on infrastructural changes will be key to projections. Information on infrastructural scenarios is also needed for gauging the climatic effects of "new" or expanding land uses related to alternative energies and of mitigation by infrastructural changes. Large-scale wind power has been shown to have local to regional temperature effects (e.g. Keith *et al*. 2004). Significant changes in global mean climate seem likely only for massive deployment of wind power; the plausibility of such scenarios needs to be assessed together with the engineering community. Methods such as white roofs have been suggested as mitigation strategies and indeed found relevant for local to regional climate (Oleson *et al*. 2010). Strong local effects are also clearly relevant for the assessment of adaptation needs. Close collaboration between engineering and climate community is needed for a complete cost-benefit analysis of such proposed mitigation tools.



Collaboration for co-benefits

The land-use / land-cover change community finds itself uniquely placed to bridge the engineering and climate research communities: they need information on both the infrastructural possibilities and on future climate to assess functional resilience such as irrigation potentials and accessibility of resources. These researchers are already working closely with climate modellers to provide land-use and land-cover information as boundary conditions for climate models to be included in the fifth assessment report of the Intergovernmental Panel on Climate Change (Hibbard *et al*. 2010). A next step could be to involve engineers during the planning stages of research to ensure that the results can better inform design, operation and management practices (Figure 2).

The infrastructure engineering community now needs to explore ways of closer interaction. It should recognise that large infrastructure such as dams, levees / reservoirs and cities can collectively affect local / regional climate through atmospheric feedbacks triggered by its very existence. It should better evaluate the long-term land-use and land-cover changes triggered by infrastructure and plan for these proactively. And it should be as inclusive as possible by considering the many potential risks beyond climate change to the functional resilience of human infrastructure. For example, rapid population growth or socio-economic issues (rural to urban migration) may force a reservoir to operate at maximum pool thereby minimizing its flood attenuation capability.

Adaptation is best served if approached locally from bottom up (e.g. Hossain *et al*. 2011). The engineering community should thus identify the types of information that could inform the optimal adaptation strategy for specific locations. For example, the engineering community of China might want to understand the potential impact of large dams like the Three Gorges – and the expected increase in urban population growth – on the Asian Monsoon. This could then be fed to researchers studying the impacts of land-use / land-cover change and thereby to climate modellers.

Political discussions and decisions on mitigation / adaptation options and alternative energy, for example, require a complete and comprehensive cost-benefit analyses that is currently lacking. There is growing recognition that closer collaboration between engineers and climate scientists is an important requirement for developing such analysis. Collaboration needs to be encouraged in every way possible. ▮

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