Institution: University of Bristol

Unit of Assessment: 17 Geography, Environmental Studies and Archaeology

Title of case study: Reducing landslide risk in urban areas in developing countries: Management of Slope Stability in Communities (MoSSaiC)

1. Summary of the impact (indicative maximum 100 words)

Management of Slope Stability in Communities (MoSSaiC) is a scientifically-based methodology developed at the University of Bristol to mitigate urban landslide risk in developing countries that has been adopted by the World Bank as part of its portfolio of disaster risk management tools. MoSSaiC centres on the efficient management of surface water and is distinct from other interventions in that it is delivered through a community-focussed programme that is rolled out in strategic incremental steps. MoSSaiC was first developed in 2004 and piloted in vulnerable urban communities in St Lucia. Since 2008 it has been implemented in additional communities in St Lucia, St Vincent and the Grenadines, and Dominica (totalling ~800 homes in 12 communities).

A direct benefit of MoSSaiC is improved slope stability, evidenced by the absence of landslides in these communities despite the exceptional rainfall of Hurricane Tomas in 2010. Indirect benefits include rainwater harvesting and reduced water bills (one community saving an estimated EC$63,000), and savings to Government of community relocation costs. As a result MoSSaiC has led to governments and international development agencies taking a radically different and more effective approach to tackling landslide hazards in vulnerable urban communities.

2. Underpinning research (indicative maximum 500 words)

Key researchers and their contributions: This research, carried out between 2004 and 2011, was led by University of Bristol researchers Professor Malcolm Anderson (Head of Department, School of Geographical Sciences 2002-05, Pro Vice-Chancellor – Research 2005-09) and Dr Liz Holcombe (PhD 2002-6, PDRA 2005-12, Lecturer 2012-). Anderson and Holcombe directed the project and contributed over 80% of the published material. Contributions from collaborators were:

From the University of Bristol:

- JP Renaud (School of Geographical Sciences) – assisted in software programming
- R Flory (School of Earth Sciences) – FLAC software modelling for investigating slope stability
- C Smith and E Wright (Centre for Market and Public Organisation) – collaborated on cost-benefit analysis of MoSSaiC projects

From the World Bank:

- M Esquivel, J Toro, F Ghesquiere (Sustainable Development Unit), and N Holm-Nielsen, T Fisseha (Disaster Risk Management Team) – contributed to the operational context by advocating for MoSSaiC within the World Bank

Centre for Ecology and Hydrology, Wallingford:

- JR Blake – wrote the code for retaining wall slope stability analysis

Context: Surface water infiltration is recognised as the dominant mechanism in triggering landslides in weathered slope materials in the humid tropics. Since the 1980s, physics-based models have been available that allow the combined effects of hydrological and geotechnical processes on slope stability to be studied. The first such model, CHASM, was developed by Anderson at the University of Bristol in 1980 and continues to provide the basis for innovative research into landslide processes, further code development, and applications to real-world slope management problems.

Nature of the research: Holcombe and Anderson produced a novel methodology (MoSSaiC) for delivering community-based landslide risk reduction to vulnerable urban areas in developing countries. The methodology is scientifically based, drawing on Holcombe and Anderson's knowledge of hydrological and geotechnical processes. This is combined with detailed local knowledge of slope features and materials provided by community residents and local engineers through community participation and risk mapping. Central to the methodology is the use of CHASM to analyse localised physical landslide processes, rainfall trigger events and engineering solutions, and inform and evaluate the risk reduction strategies and interventions. While MoSSaiC is founded in science it is the Bristol team's innovative approaches – being community-focussed, delivering on-the-ground solutions, and enabling evidence-based policy change – that have led to

its success and sustainability and the impacts outlined in this case study.

In 2003/2004, Holcombe and Anderson extended CHASM's capability from predicting landslide hazard to quantifying risk. New code was developed to model post-failure slope geometries, landslide run-out, debris removal, slope re-grading, and associated economic costs. The integrated model enabled different slope investment scenarios to be tested for multiple slopes over budget cycles and design lifetimes via an integrated cost-benefit analysis module.

In 2004, at the request of the Government of St Lucia, Holcombe and Anderson developed a prototype methodology (utilising CHASM) to address landside risk in unauthorised communities. The end-to-end methodology was designed to stabilise vulnerable hillsides by the efficient management of surface water [1]. The approach recognised the critical importance of scale in urban landslide hazard assessment [1]. CHASM confirmed the driving destabilising mechanism to be rainfall and waste-water infiltration controlled by altered natural drainage patterns and micro-topography [2, 3] – processes occurring at a resolution too fine to be identified by conventional GIS-based landslide hazard assessment methods.

The pilot research in the Eastern Caribbean provided the context for further development of CHASM to represent localised human and physical aspects of urban landslide risk, including point water sources and structural loading. A progressive landslide in one community provided a test case for the prototype code. CHASM analysis, driven by observed rainfall, successfully replicated the timing, location and travel distance of the landslide and confirmed the role of surface water convergence in triggering and continuing to mobilise the failure. Local laboratory apparatus for measuring soil strength was benchmarked against an equivalent, state-of-the-art direct shear box at the University of Bristol, and parameter uncertainty was accounted for in the simulations. Scenario testing indicated that reducing infiltration by 25% and lowering the water table by four metres would stabilise the slope. Accordingly, drains were designed and constructed to intercept surface water and household rainwater from roofs [3]. The new drains were observed to intercept 70% of upslope surface water run-off, reducing convergence, infiltration and ground water levels at the site of the landslide [3]. Drawing out and developing the expertise of residents, local contractors and government engineers ensured uptake of the broad concepts of slope water management as a means to reduce landslide risk.

3. References to the research (indicative maximum of six references)

Outputs:

[1] Anderson MG, Holcombe EA. 2006. Sustainable landslide risk reduction in poorer countries. *Proc Institution of Civil Engineers, Engineering Sustainability* 159: 23-30. [doi:10.1680/ensu.2006.159.1.23].

[2] Anderson MG, Holcombe EA. 2007. Assessing slope stability in unplanned settlements in developing countries. *Journal of Environmental Management* 85(1): 101-111. [doi:10.1016/j.jenvman.2006.08.005].

[3] Anderson MG, Holcombe EA, Flory R & Renaud J-P. 2008. Implementing low-cost landslide risk reduction: a pilot study in unplanned housing areas of the Caribbean. *Natural Hazards* 47 (3): 297-315. [doi:10.1007/s11069-008-9220-z].

[4] Anderson MG, Holcombe L, Esquivel M, Toro J, Ghesquiere F. 2010. The efficacy of a programme of landslide risk reduction in areas of unplanned housing in the Eastern Caribbean. *Environmental Management* 45(4): 807-821. [doi: 10.1007/s00267-010-9431-4].

[5] Anderson MG, Holcombe EA, Blake JR, Ghesquiere F, Holm-Nielsen N, Fisseha T. 2011. Reducing landslide risk in communities: evidence from the Eastern Caribbean. *Applied Geography* 31: 590-599. [doi:10.1016/j.apgeog.2010.11.001].

[6] Holcombe EA, Smith S, Wright E, Anderson MG. 2011. An integrated approach for evaluating the effectiveness of landslide hazard reduction in vulnerable communities in the Caribbean. *Natural Hazards* 61 (2): 351-385. [doi:10.1007/s11069-011-9920-7]

[7] Anderson MG, Holcombe EA. 2013. *Managing disasters in small steps: community-based landslide risk reduction.* World Bank, Washington DC 445pp. ISBN 978-0-8213-9456-4

External endorsements of quality of the research and its outputs:

- In 2007, output [1] awarded the Trevithick Award by the Institution of Civil Engineers, London.
- CHASM Software is recognised internationally as an industry-standard product with the US-

based Scientific Software Group, which has been marketing the software since 2000 and has achieved CHASM sales in more than 17 countries.
- In 2010, CHASM won the Random Hacks of Kindness event Hacking for Humanity, which is sponsored by NASA, the World Bank, Google, Microsoft and Yahoo [a].

4. Details of the impact (indicative maximum 750 words)

Nature of the impact: People living below the poverty line in developing countries are often pushed to the urban fringes, into unplanned settlements. Houses are built where no municipal infrastructure exists, on land that is often subject to high levels of landslide hazard. In the best-case scenarios, landslides cause disruption, loss and damage of homes and possessions; in the worst-cases they cause the loss of life. For governments, landslides can be expensive in terms of community re-housing and relocation costs.

The MoSSaiC methodology, which provides a sustainable and holistic approach to landslide risk reduction, has led to four main impacts: i) significant reduction of landslide risk for people living in unplanned settlements in developing countries; ii) indirect benefits to communities as a result of the water management solutions implemented; iii) economic benefits to governments; and iv) uptake of the MoSSaiC methodology by the World Bank in order to extend the reach of the impact to other countries where urban landslide risk is most acute. World Bank endorsement of the MoSSaiC methodology states: "Your initiative, 'Management of Slope Stability in Communities (MoSSaiC) represents a novel approach to reducing landslide risk. There are two areas in particular where MoSSaiC makes a significant contribution, namely community engagement and the associated on-the-ground delivery of improved hill-slope drainage to bring about improved slope stability." [b]

i) Significant reduction of landslide risk for people living in unplanned settlements in developing countries: Since 2008, approximately 800 homes across 12 communities have benefited from MoSSaiC interventions in three island states in the Caribbean. In 2010, these direct benefits were realised when St Lucia felt the effects of Hurricane Tomas, which produced a 1 in 500-year, 24-hour rainfall event [5]. The World Bank noted that "in the aftermath of Hurricane Tomas (October 2010), there were numerous landslides in St. Lucia due to the extreme rainfall. None were reported in any of the communities with MoSSaiC interventions." [b]

ii) Indirect benefits to communities as a result of the on-the-ground water management solutions implemented: A cost-benefit analysis of a MoSSaiC project in St Lucia surveyed residents of the community to identify and value the direct and indirect benefits the community had received as a result of the new surface water management and drainage infrastructure [6]. Direct benefits were the probable avoided costs of future landslide damage to houses. Indirect benefits included: lower water bills through the harvesting of intercepted rainwater from rooftops; improved access to and from the community due to reduced flooding and associated debris on footpaths; and therefore fewer days of work missed and less time spend clearing debris. Together, these benefits were valued at EC$12,705 annually [6]. In the eight years that the measures have been in place, this amounts to over EC$100,000 in estimated benefits to this pilot community (over EC$63,000 since 2008). In addition, more than 80% of programme funds are spent in the communities, which not only creates employment opportunities (e.g., 25 residents were employed on the pilot project [c, p24]) but also fosters ownership of the programme within the community [2].

iii) Economic benefits to governments: A cost-benefit analysis of the pilot project in St Lucia demonstrated that the benefits of implementing landslide mitigation measures in that community outweighed the costs 2.7:1 [6].

iv) Uptake of the MoSSaiC methodology by the World Bank: The Latin America and the Caribbean Disaster Risk Management team of the World Bank has been collaborating closely with the MoSSaiC team since 2009, when they funded the Second Disaster Mitigation Programme in St Lucia, bringing the MoSSaiC methodology to an additional six communities. In 2009, the MoSSaiC methodology was featured in the World Bank's *World Development Report 2010* [d, p327] and in October 2011 it was one of 20 projects selected for the *Aid Effectiveness Showcase* in Washington, DC [e]. MoSSaiC also features on the World Bank's Latin America and the Caribbean website, *Results in Action* [f]. In 2013, the World Bank published a book co-authored by Anderson and Holcombe entitled *Community-based landslide risk reduction – managing disasters in small*

steps [7] that will later be published in Spanish [b, f]. "The work already has clear evidence of impact in the field of community-based disaster risk reduction," said Holm-Nielsen [b]. "The aim is to maximize the impact of the approach in those countries where landslide risk is most acute, not only through the use of the book, but through the development of future additional resources with the support of the World Bank's Latin America and Caribbean Disaster Risk Management team."

Reach of impact: Since 2008 the MoSSaiC methodology has benefitted ten communities in St Lucia and one each in Dominica, and St Vincent and the Grenadines [c, p25]. In 2011, it was introduced to Jamaica through a programme of community-based projects costing US$2.37 million, funded by the World Bank [g] and implemented by the Office of Disaster Preparedness and Emergency Management. It is expected that the reach of the impact will be greatly extended with the uptake of the methodology by the World Bank and publication of the Anderson and Holcombe book in Feb 2013 [7].

Dissemination of the research: The research and mitigation methodology was delivered using a process of strategic incrementalism with a view to maximising the sustainability of project outcomes (Anderson and Holcombe, 2011). Key steps in disseminating MoSSaiC included:

- 2004. Government of St Lucia formalises MoSSaiC Management Committee [h, p26-27; i, p17].
- 2007. MoSSaiC recognised by Institution of Civil Engineers, London through Trevethick Prize.
- 2007. MoSSaiC community-to-community transfer of knowledge through annual conferences.

These actions led directly to the following impacts since 2008:

- 2008-2009. International agencies (USAID, UNDP) funded MoSSaiC in the Eastern Caribbean.
- 2009-2011. World Bank funded MoSSaiC projects in St Lucia and included MoSSaiC as a case study in the World Development Report 2010 [d, p327].
- 2009-ongoing. World Bank adopts MoSSaiC as an urban disaster mitigation method appropriate for scaling up to other developing countries in the humid tropics [7]

5. Sources to corroborate the impact (indicative maximum of 10 references)

[a] NASA (2010) *Global Hackers Marathon Creates Solutions to Global Problems.* Office of the Chief Information Officer, NASA. www.nasa.gov/offices/ocio/ittalk/07-2010_rhok.html

[b] Holm-Nielsen, N. (Regional Coordinator – Disaster Risk Management, Sustainable Development Department, Latin American and the Caribbean Region, The World Bank). Letter to M. Anderson. October 19, 2012.

[c] US AID (2006) *Caribbean regional community revitalization and disaster mitigation program*: Final Report. Planning and Development Collaborative International, Washington DC. http://pdf.usaid.gov/pdf_docs/PDACI379.pdf

[d] The World Bank (2009) *World Development Report 2010: Development and Climate Change*. Available online: http://siteresources.worldbank.org/INTWDR2010/Resources/5287678-1226014527953/Chapter-8.pdf

[e] World Bank (2011) *Aid effectiveness showcase*, World Bank Main Complex, Washington DC, October 2011. http://www1.worldbank.org/operations/aideffectiveness/Showcase4.html

[f] World Bank (2012) *Saint Lucia: From Landslides to Stability.* http://go.worldbank.org/FM2UZNLT30

[g] Jamaica: Jamaica Observer. 26th October 2011. MoSSaiC featured in article entitled: *Landslide risk reduction project coming*. http://www.jamaicaobserver.com/news/Landslide-risk-reduction-project-coming_9778720

[h] Government of Saint Lucia (2006) *Landslide Response Plan.* Revised August 2006. http://archive.stlucia.gov.lc/nemp/plans/LandslidePlan.pdf

[i] Government of Saint Lucia (2006) *Emergency Housing Management Policies and Guidelines for Saint Lucia.* http://archive.stlucia.gov.lc/nemp/policies/EmergencyHousingPolicy.pdf

International Press:

- New York Times 18th January 2010. MoSSaiC featured in article entitled: *Managing disasters in small steps*.http://www.nytimes.com/2010/01/19/science/19reli.html?pagewanted=all

Advocacy to UK Government and industry:

- SETSquared Partnership, Changing World Showcase, Westminster, London. MoSSaiC invited lecture. *Predicting and cutting landslide risk in developing countries*. 13th October 2010. http://www.setsquared.co.uk/impact/environment-case-studies/cutting-landslide-risk