BEFORE THE HEARING PANEL APPOINTED BY CANTERBURY REGIONAL COUNCIL

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER OF	Application CRC 190445 by Christchurch City Council for a discharge permit to discharge stormwater into land and to water and a coastal permit to discharge stormwater to coastal water from the reticulated stormwater network

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STATEMENT OF EVIDENCE OF ADRIANNA MARIE HESS

Dated 24 October 2018

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INTRODUCTION

1 My full name is Adrianna Marie Hess. I hold the qualification of Master of Urban Resilience and Renewal from the University of Canterbury. I am submitting evidence on behalf of myself.

2 Over the past two years, I have studied the river and coastal geomorphic processes of Canterbury, and how they interact with urban environments. I have an understanding hydrology and hydrodynamics, flooding from coastal, fluvial and pluvial sources, catchment processes, river mouth environments, sea level rise, and theoretical and numerical modelling, all of which are essential for effective resource and environmental management. I have reviewed urban resilience strategies in Vietnam, the United Kingdom, the United States, and New Zealand.

3 I have collaborated extensively with pavement engineers in Australia, drainage engineers and commercial building inspectors in New Zealand, and the University of Chicago's Urban Data Visualisation Laboratory concerning the implementation of Green Infrastructure and Sustainable Drainage Systems.

4 I am generally familiar with the New Zealand Building Code, as well as methods of approving Alternative Solutions for implementation under the Building Consent Authority.

5 I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. My qualifications as an expert are set out above. Other than those matters identified within my evidence as being from other experts, I confirm that the issues addressed in this brief of evidence are within my area of expertise.

6 I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

7 In 2016, I reviewed Green Infrastructure and Sustainable Urban Drainage Systems installations all over the world, with case studies in Portland, Oregon and Chicago, Illinois. The conclusions of this review were included in my original submission. For completeness I **attach** a copy of my original submission as "Attachment A".

8 My evidence will be restricted to:

- Three types of Sustainable Urban Drainage Systems (SUDS) installations, also referred to as Green Infrastructure (GI)
- Benefits and Limitations of SUDS
- Recommendations to amend the wording of some of the present recommended conditions and to propose a number of new conditions to CRC190445.

BACKGROUND INFORMATION ON SUSTAINABLE DRAINAGE SYSTEMS

9 The building of traditional urban infrastructure involves the conversion of pervious land (i.e., soil) to impervious cover such as asphalt or concrete roads, corrugated roofing, etc., which

both stops infiltration and speeds up stormwater runoff. During storm events, pollutants such as decomposed litter, motor oil, herbicides, etc., which settle on impervious surfaces, flush directly into aquatic ecosystems (Yang et al., 2015) where they cause non-point source pollution and sedimentation. In the "Assessment of Current and Future Stormwater Contaminant Load for Christchurch", Golder (2018) acknowledged this problem, and stated that most of Christchurch's stormwater runoff will enter urban streams and any dissolved or suspended contaminants will affect stream water quality.

10 One of the emerging strategies to mitigate stormwater runoff is to implement Sustainable Urban Drainage Systems (SUDS), such as pervious concrete, pervious asphalt, or rain gardens. SUDS capture and treat stormwater naturally through infiltration, rather than discharging contaminated runoff directly to waterways via drainage systems. SUDS (as an infiltration system) are described by Golder (2018) as one Best Practice scenario, where the amount of stormwater entering the system is reduced before it needs treatment, and that the treatment efficiency of areas that discharge to ground is assumed to be 100% (Golder, 2018).

OVERVIEW OF PERVIOUS CONCRETE AND PERVIOUS ASPHALT (PERVIOUS PAVEMENTS)

11 Pervious Concrete recreates the natural hydrological system, where rainwater soaks and filters through the earth, and replenishes the groundwater table. Pervious concrete contains no fine aggregate (sand), and the cement binder creates a system of interconnected voids that promote rapid drainage of water (Tennis et al., 2004; ACI, 2010). Its' surface is smooth enough for both foot and automobile traffic, even though 15 – 25 percent voids are achieved in the hardened concrete (FHWA, 2012). *Figures 1* and *2* show typical cross sections of pervious concrete pavement.

Figure 1: Pervious concrete surface layer demonstration (Harrison, 2011)

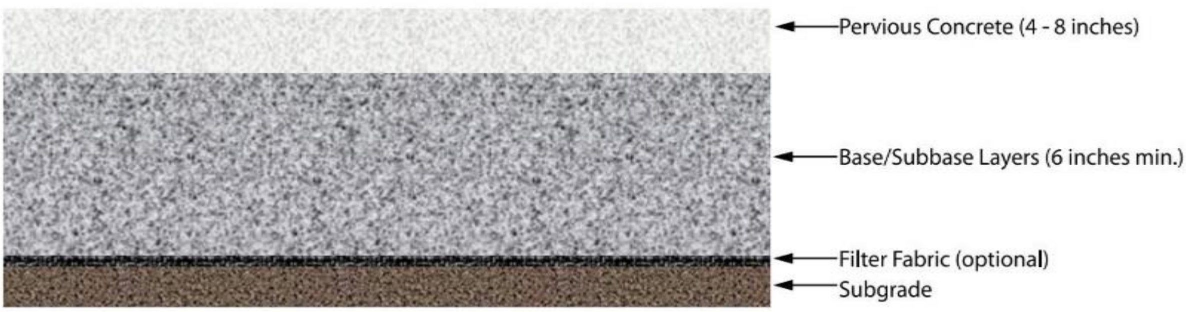

Figure 2: Pervious concrete pavement cross section. Recommended subbase layer of SUDS installation depth to be 1 meter containing 40% void volume aggregate (adapted from EPA, 2010)

BENEFITS OF PERVIOUS PAVEMENTS

12 The major benefits of pervious concrete and pervious asphalt are reduced stormwater runoff, reduced pollution and nutrients in waterways, enhanced Health & Safety benefits, and noticeable reductions in the Urban Head Island (UHI) effect. With high levels of permeability, “first flush” rainfall (that part of the runoff with a higher contaminant concentration) filters into the ground, and as it drains, contaminants are decomposed by microbial activity, which then improves water quality (FHWA, 2015). When applying these systems to “contaminated land”, the stone reservoir beneath the paving course can be additionally seeded with commercially available microbes, which are designed to breakdown contaminants. This microbial population is known as “biomass”, which breaks down contaminants, particularly in oil spill clean-up. One study showed a reduction in petroleum contamination in the effluent to 2.4% of the oil applied to pavement (22g/m^2/year from deposition of 900g/m^2/year) (Pratt et al., 1999).

13 Pervious pavements provide Health & Safety benefits by reducing the amount of standing water on pavements, which cause both hydroplaning and reduced visibility due to splash/spray potential. In addition, these pavements reduce road noise emissions due to the open structure that absorbs noise at the tire-pavement interface, which benefit both road workers and the surrounding community (ACI, 2010). Reductions in the need for de-icing salts have also been realised, as melting snow absorbs through the voids rather than refreezing as ice. The University of New Hampshire Stormwater Center reported a 75% or greater reduction of de-icing salt applications. While the system does not remove chloride, the drastic reduction of de-icing chemicals required is an effective method for reducing chloride pollution (Roseen et al., 2014). There have been concerns about the use of pervious concrete in areas subjected to severe freeze– thaw cycles, however, available field performance data from a number of projects indicate no signs of freeze–thaw damage (Delatte et al. 2007; ACI 2010).

14 Recent research has identified pervious pavements as a “cool pavement technology.” Due to their high air-void structure, these pavements can mitigate the Urban Heat Island effect by reducing stored pavement energy and allowing for rapid cooling via evaporation and convective airflow (Cambridge, 2005; Li et al. 2013; Stempihar et al., 2012; EPA, 2008).

LIMITATIONS OF PERVIOUS PAVEMENTS

15 Along with its many benefits, there are some limitations associated with pervious **concrete**. First, the vast majority of pervious **concrete** projects constructed to date were designed to carry light automobile traffic only, ranging from driveways and parking lots to residential streets, alleys, and other low-volume roads (FHWA, 2015; Tennis et al. 2004). Within these applications, pervious concrete has been used as the surface course, as a drainable base course (often in conjunction with edge drains to provide subsurface drainage), or as a drainable shoulder (to help provide lateral drainage to a pavement and prevent pumping) (FHWA, 2012).

16 However, as it is a more robust installation, with diligent engineering the use of pervious **asphalt** pavements for highways is possible for some situations (FHWA, 2012). There have been some porous **asphalt** pavements used for road and highway pavements such as the

Arizona Avenue/SR 87 in Chandler, Arizona, and Maine Mall Road in South Portland, Maine (Palmer, 2012; Peabody, 2010). However, the use of asphalt should be avoided where possible, as petroleum products experience volatile price fluctuations and exposure to oxidized bitumen emissions is probably carcinogenic to humans (McClean et al., 2011; Olsson et al., 2010; Rhomberg et al., 2015).

17 Pervious concrete exhibits significantly different characteristics from conventional concrete, such as material characteristics (primarily lower paste contents and higher void contents) and hardened properties (notably density and strength). As a result, the current established methods of quality control/quality assurance (e.g., slump, strength, air content) are in many cases not applicable (ACI, 2010). Therefore, alternative methods such as the Taguchi method, should be applied to assess the compressive, splitting-tensile, and flexural strength of pervious concrete, in order to optimize mixture design and performance (Joshaghani et al., 2015).

18 Pervious concrete, when installed as a SUDS installation excavated to 1000mm deep, can be more expensive than conventional concrete, and in Christchurch, on average will cost 15% more to install[1]. It should be noted that these figures were calculated without accounting for drainage system installation. In addition, both pervious concrete and pervious asphalt pavements are recommended to receive annual maintenance with regenerative air sweeper trucks. One study showed that without maintenance, porous pavements reach a total loss of porosity after nine years (Sañudo-Fontaneda et al., 2018). However, when tested in the field, Firth found that one residentail driveway that had not received maintenance for 10 years still operated a permeability rate of 310mm/hr, which is above the Coucil requirement at 120mm/hr. Firth's hydrovac system, which is specifically designed to clean pervious concrete, increased permeability in this case to 5,500mm/hr[2].

SUMMARY OF BENEFITS AND LIMITATIONS OF PERVIOUS PAVEMENTS

19 While many cities in New Zealand utilise rain gardens (Auckland Council, n.d.) in SUDS infrastructure, pervious pavements have not. The benefits often outweigh the limitations of this infrastructure, particularly when installation costs are reduced by eliminating drainage installation and hydro-excavation charges for connecting to mains. Further savings may be realised as a result of flood prevention both during large storm events and post-earthquake damage, which uplifts or shears delicate drainage pipes.

Benefits/Advantages	Limitations/Disadvantages
• Reduction in contaminants and excess nutrients in water runoff and sediment loading (Auckland Council, 2017; Boogaard et al., 2014; Lebens, 2012; Houle et al., 2013) • Reduction in Stormwater runoff volume (Lebens, 2012) • Cost effective technology for stormwater management, by reducing need for	• Pavement structure drainage course initial costs are often higher (shown to be 15% in Christchurch[1]); however, this may be offset by cost reductions realized from avoiding drainage infrastructure installation (Houle et al., 2013) • Potential clogging with dirt and organic debris requiring specialized maintenance such as regenerative air sweepers other

1 Statement based on findings in Appendix C: Comparison Cost of Pervious and Conventional Concrete Installations in Christchurch. Drainage systems not included in conventional concrete quote comparison, and may offset the 15% premium shown above.

2 Findings taken from Appendix D: Firth Permeable Pavement Presentation.

Benefits/Advantages	Limitations/Disadvantages
drainage structures (Houle et al., 2013; EPA, 2014) • Recharges groundwater supplies (Starke et al., 2010) • Enhanced safety via improved wet-weather visibility and reduced tire spray and hydroplaning (ACI, 2010; Lebens, 2012) • Absorption of noise from tires and engines (ACI, 2010; Lebens, 2012) • Cools stormwater temperature during summertime before discharge and mitigates Urban Heat Island effects (Lebens, 2012) • Improves water and oxygen transfer to nearby plant roots (CTC & Associates, 2012) • Resilience to earthquakes through independence from drainage pipes • Porous pavements can be constructed to treat areas at risk of oil spill contamination if additional biomass is applied (Lebens, 2012; Pratt et al., 1999; FHWA, 2015) • Snow and ice melts faster, reduction in de-icing salts (Lebens, 2012; Roseen et al., 2014) • Credits in green construction rating systems (i.e., LEED; Greenroads; IgCC)	cleaning mechanisms (UNHSC, 2012; Sañudo-Fontaneda et al., 2018) • Limited use for heavy loading areas where sharp turns are probable (FHWA, 2015) • Some variation from standard construction practices (FHWA, 2012)

OVERVIEW OF RAIN GARDENS

Like pervious pavements, rain gardens demonstrate the ability to retain both suspended solids and mineral oil through reducing peak stormwater discharge (see *figures 3* and *4* below). In addition to the benefits of infiltration, rain gardens support native biodiversity, ecological and hydrological cycle restoration, carbon sequestering, and improves the mental health of residents (Everett et al., 2016; Zhao et al., 2016).

Figure 3: Rain garden cross section

Figure 4: Example of a rain garden in New York City

22 Rain gardens are the most beneficial when applied to existing impervious concrete roadsides, or to areas where permeable pavements are not applicable (such as intersections or heavily trafficked highways). Through hydrological modelling, Zellner et al. (2016) found that when rain gardens are placed adjacent to conventionally paved roads, incorporating 30% rain gardens into impervious infrastructure may prevent flooding during a 100-year storm event in Christchurch[3]. It should be noted that the marginal benefits of incorporating rain gardens in urban environments greatly decreases above 30% (Zellner et al., 2016). I fully endorse CCC's incorporation of rain gardens into their proposed stormwater drainage plans, and I believe that they should be implemented at higher ratios than what is currently planned.

COMPLYING WITH NEW ZEALAND BUILDING CODE - CLAUSE E1 SURFACE WATER

23 When used as SUDS, pervious pavements and rain gardens fall under the New Zealand Building Code (NZBC) Clause for Surface Water E1 (the full provisions for NZBC E1 are shown in *Appendix B* below). Both of these installations achieve NZBC objective "E1.1 (a) Safeguard people form injury or illness, and other property from damage, caused by surface water". Permeable pavements also achieve objective "E1.3.3 (f) avoid the likelihood of damage from superimposed loads or normal ground movements", as these systems are resilient to earthquake (superimposed loads) and normal traffic loading (normal ground movements).

ACHIEVING THE PURPOSE OF THE RESOURCE MANAGEMENT ACT

24 SUDS achieve the purpose of the Resource Management Act 1991 (the Act), the objective of which is to promote sustainable management of natural and physical resources. Furthermore, utilising SUDS, which provides natural filtration of contaminants through infiltration, will help CCC to more effectively achieve the purpose of RMA Section "15(1) No person may discharge any - (a) contaminant to water or into water, and (b) contaminant onto or into land in circumstances which may result I that contaminant (or any other contaminant emanating as a result of natural processes from that contaminant) entering water". I believe that by continuing to build urban infrastructure in a way that allows the concentration of contaminants within stormwater systems to enter aquatic environments, CCC is in direct conflict with the objectives of the Act.

RECOMMENDATIONS

25 The application-oriented frameworks required in mainstreaming SUDS are still lacking (Connop et al., 2016). Therefore, I believe that SUDS will be most effectively implemented and observed at a Regional Council level in order to empirically observe the effects on stormwater quantity and quality. While permeable pavements are not recognised as an Acceptable Solution under the NZBC, these installations meet the Alternative Solution criteria as set out in NZBC Clause E1. Environment Canterbury (ECan) can assist Christchurch City Council (CCC) in creating this framework by requiring the addition of permeable pavements in their Building Consent Authority policies and procedures.

3 Statement extrapolated from findings in Chicago, Illinois, where silty loamy alluvial soil samples, current drainage systems, flood flow probabilities, and 100-year storm event volumes (NIWA, 2017) are comparable.

26 The US Department of Transportation recommends that as best practice, the ratio of pervious pavement areas to impervious areas should be 1:5 (20%) for most conditions (FHWA, 2015). Zellner et al. (2016) recommends a maximum ratio of 1:3 (33%), as studies show that the marginal benefits of SUDS greatly decrease above this figure. As a starting point, I recommend that within the first 10 years of granting this consent, CCC should be required to achieve a 1:20 (5%) incorporation of SUDS where impervious areas are concentrated in Christchurch. Installations could include, but are not limited to, bike lanes, foot paths, driveways and parking areas. This timeline accommodates training staff on how to install and maintain SUDS structures, and it also takes into account the cumbersome process of building infrastructure. I believe that Christchurch should set a goal of 1:30 (33%) SUDS incorporation in urban areas at the end of 30 years. Realistically, best management practices should be no lower than that of the US Department of Transportation at 1:5 (20%).

27 My recommendation are as follows:

- Require CCC to achieve a 1:20 (5%) ratio of SUDS to impervious surface in central city Christchurch by 2028, and set a goal for a 1:3 (33%) ratio by 2043
- Require CCC to add permeable concrete and permeable asphalt as Acceptable Solutions within its policies and procedures as a Building Consent Authority in order to decrease barriers to implementation
- Work with modelling tools developed by the University of Chicago (or other) to inform the development of planning and regulatory recommendations for stormwater management with an understanding of how SUDS may work (or not) in a variety of situations
- Recommend that permeable concrete subbase aggregate be seeded with "biomass" to treat areas that receive petroleum contamination
- Advise CCC to partner with University structural engineering students to study the benefits, limitations, lifecycle, etc., of SUDS

RECOMMENDED CHANGES TO EXISTING CONDITIONS

28 I recommend some amendments to the Resource Consent Application and Assessment of Effects on the Environment (June 2015). These amendments are in response to the matters discussed earlier in this evidence. The text recommended for deletion is identified as ~~strike through~~ and recommended additional text is <u>underlined</u>.

29 Comprehensive Stormwater Network Discharge Resource Consent (CSNDC) Application Section 1.4 CSNDC Consent Objectives:
1.4.1 Waterways
Receiving environment objectives for waterways can be summarised as:
1. Enhance ecological values.
2. Decrease sediment input to prevent adverse effects on water clarity and aquatic biota.
3. Reduce copper, lead and zinc levels in surface water to prevent adverse effects on aquatic biota.
4. Reduce nutrient levels to limit excessive growth of macrophytes and filamentous algae.
5. Improve sediment quality to prevent adverse effects on aquatic biota.
6. Enhance tangata whenua values and provide for the values and interests of Ngai Tahu associated with freshwater resources.

7. Prioritise neighbourhood-scale extra-over detention Sustainable Drainage System methods, including permeable concrete, permeable asphalt, and rain gardens;

30 I further recommend that the CSNDC Application requires in the Ōtākaro / Avon River Stormwater Management Plan, a minimum of 5% but optimally 33% surface area allocation to SUDS, in particular pervious pavements, in all new developments that will result in impervious infrastructure. I believe that a 5% incorporation of SUDS in urban built environments may be reasonably achieved throughout the Avon River catchment area by the end of 2028.

CONCLUSIONS

31 Implementing permeable concrete, permeable asphalt, and rain gardens, will allow CCC to fulfil its obligations under application CRC 190445, where the “discharges will occur in accordance with Stormwater Management Plans that **demonstrate the means by which the quality of stormwater discharges will be progressively improved**” (ECan, 2018). Moving stormwater management plans toward infiltration and away from conventional drainage systems will improve the quality of stormwater before it reaches aquatic ecosystems, thereby reducing non-point source pollution and sedimentation.

Adrianna M. Hess, MSc.

24 October 2018

REFERENCES

American Concrete Institute (ACI). (2008). Specification for Pervious Concrete Pavement. ACI 522.1-08. ACI, Farmington Hills, MI.

Auckland Council (2017). Swales and Filter Strips Construction Guide. *Stormwater Device Information Series.* Retrieved from http://www.aucklandcouncil.govt.nz/EN/environmentwaste/stormwater/Documents/swaleconstructionguide.pdf

Auckland Council. (n.d.). Rain Garden Construction Guide, Stormwater Device Information Series. Retrieved from https://www.aucklandcouncil.govt.nz/environment/stormwater/docsconstructionguides/rain-gardens-construction-guide.pdf

Boogaard, F., Lucke, T., & Beecham, S. (2014). Effect of age of pervious pavements on their infiltration function. *CLEAN – Soil, Air, Water, 42*(2), 146-152. 10.1002/clen.201300113

Cambridge Systematics, Inc. (Cambridge). (2005). Cool Pavements Report. Environmental Protection Agency, Washington, DC.

Connop, S., Vandergert, P., Eisenberg, B., Collier, M. J., Nash, C., Clough, J., & Newport, D. (2016). Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. *Environmental Science & Policy, 62*, 99-111. doi:10.1016/j.envsci.2016.01.013

CTC & Associates Inc. (2012). Porous Asphalt Performance in Cold Regions. Report 2012-12TS. Minnesota Department of Transportation, St. Paul, Minn. Available online at www.dot.state.mn.us/research/TS/2012/201212TS.pdf

Delatte, N., D. Miller, and A. Mrkajic. (2007). Portland Cement Pervious Concrete Pavement: Field Performance Investigation on Parking Lot and Roadway Pavements. Final Report. RMC Research & Education Foundation, National Ready Mixed Concrete Association, Silver Spring, MD.

Environment Canterbury Regional Council (ECan). (2018). Christchurch City Council – Comprehensive Stormwater Network Discharge. Retrieved from https://www.ecan.govt.nz/do-it-online/resource-consents/notifications-and-submissions/current-consent-projects/christchurch-city-council-comprehensive-stormwater-network-discharge/

Environmental Protection Agency (EPA). (2010). Pervious Concrete Pavement. EPA, Washington, DC. Available online at http://cfpub.epa.gov/npdes/stormwater/menuofbmps/ index.cfm?action=browse&Rbutton=detail&bmp=137&mi nmeasure=5.

Environmental Protection Agency (EPA). (2014). The Economic Benefits of Green Infrastructure: A Case Study of Lancaster, PA. EPA 800-R-14-007. U.S. Environmental Protection Agency, Washington, D.C. Available online at 10 | Porous Asphalt Pavements with Stone Reservoirs FHWA-HIF-15-009 water.epa.gov/infrastructure/greeninfrastructure/upload /CNT-Lancaster-Report-508.pdf

Environmental Protection Agency (EPA). (n.d.). National Menu of Stormwater Best Management Practices: Porous Asphalt Pavements. Available online at https://water.epa.gov/polwaste/npdes/swbmp/Porous-AsphaltPavement.cfm

Everett, G., Lamond, J., Morzillo, A. T., Chan, F. K. S., & Matsler, A. M. (2016). Sustainable drainage systems: Helping people live with water. *Proceedings of the Institution of Civil Engineers - Water Management, 169*(2), 94-104. doi:10.1680/wama.14.00076

Federal Highway Administration (FHWA), United States Department of Transportation. (December, 2012). Advanced Concrete Pavement Technology Tech Brief FHWA-HIF-13-006. Retrieved from https://www.fhwa.dot.gov/pavement/concrete/pubs/hif13006/hif13006.pdf

Federal Highway Administration (FHWA), United States Department of Transportation. (April, 2015). Porous Asphalt Pavements with Stone Reservoirs. Retrieved from: https://www.fhwa.dot.gov/pavement/asphalt/pubs/hif15009.pdf

Golder Associates (NZ) Limited. (July, 2018). Assessment of Current and Future Stormwater Contaminant Load for Christchurch. Retrieved from https://www.ecan.govt.nz/assets/Uploads/Consents-Images/CCC-stormwater-PDFs-Temp./CRC190445CSNDCadditionalinformationChristchurchContaminantLoadModelReportSchedule2toconditions.PDF

Hoang, L., & Fenner, R. A. (2016). System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal, 13*(7), 739-758. doi:10.1080/1573062X.2015.1036083

Houle, J.J., R.M. Roseen, T.P. Ballestero, T.A. Puls, & J. Sherrard Jr. (2013). Comparison of Maintenance Cost, Labor Demands, and System Performance for LID and Conventional Stormwater Management. Journal of Environmental Engineering, Vol. 139, No. 7, pp. 932– 938. DOI: 10.1061/(ASCE)EE.1943-7870.0000698

Joshaghani, A., Ramezanianpour, A. A., Ataei, O., & Golroo, A. (2015). Optimizing pervious concrete pavement mixture design by using the taguchi method. *Construction and Building Materials, 101*, 317-325. doi:10.1016/j.conbuildmat.2015.10.094

Lebens, M. (2012). Porous Asphalt Pavement Performance in Cold Regions. Report 2012-12. Minnesota Department of Transportation. St. Paul, Minn. Available online at www.dot.state.mn.us/research/documents/201212.pdf

Li, H., J.T. Harvey, T.J. Holland, & M. Kayhanian (2013). The Use of Reflective and Pervious Pavements as a Potential Practice for Heat Island Mitigation and Stormwater Management. Environmental Research Letters, Vol. 8, No. 1. DOI: 10.1088/1748-9326/8/1/015023

Lieberherr-Gardiol, F. (2008). Urban sustainability and governance: Issues for the twenty-first century. *International Social Science Journal, 59*(193-194), 331-342. doi:10.1111/j.1468-2451.2009.01670.x

Margetts, B., Christensen, P., Marshall, W., Callander, P., Pauling, C. (June 2015). Draft Environmental Monitoring Programme for the Comprehensive Stormwater Network Discharge Consent for Otautahi/Christchurch City and Te Pataka o Rakaihautu/Banks Peninsula. Retrieved from https://www.ecan.govt.nz/assets/Uploads/Consents-Images/CCC-stormwater-PDFs-Temp./CRC190445ApplicationDLDWcomprehensiveChristchurchCityBanksPeninsulaEnvironmentalmonitoringprogramme-1.PDF

McClean, M. D., Kelsey, K. T., Sison, J. D., Quesenberry, C. P., Wrensch, M. R., & Wiencke, J. K. (2011). A case–control study of asphalt and tar exposure and lung cancer in minorities. American Journal of Industrial Medicine, 54(11), 811-818. doi:10.1002/ajim.21007

NIWA. (2017). High Intensity Rainfall Design System Calculator Version 3. *National Institute of Water and Atmospheric Research.* https://hirds.niwa.co.nz/

Olsson, A., Kromhout, H., Agostini, M., Hansen, J., Lassen, C. F., Johansen, C., Boffetta, P. (2010). A Case—Control study of lung cancer nested in a cohort of European asphalt workers. Environmental Health Perspectives, 118(10), 1418-1424. doi:10.1289/ehp.0901800

Palmer, M.A. (2012). Design and Construction of Porous Asphalt Pavements. Presented at WSU Puyallup Technical Workshop Series — Pervious Paving Design, April 24, 2012.

Peabody, D. (2010). Performance of a Porous Pavement System on the Maine Mall Road in South Portland: Construction and Interim Report — December 2010. Technical Report 10-05. Maine Department of Transportation, Transportation Research Division, Augusta, Maine. Available online at http://ntl.bts.gov/lib/52000/52400/52486/report1005ci1.pdf

Pratt, C. J., Newman, A. P., & Bond, P. C. (1999). Mineral oil bio-degradation within a pervious pavement: Long term observations. Water Science and Technology, 39(2), 103. doi:10.1016/S0273-1223(99)00013-X

Rhomberg, L. R., Mayfield, D. B., Goodman, J. E., Butler, E. L., Nascarella, M. A., & Williams, D. R. (2015). Quantitative cancer risk assessment for occupational exposures to asphalt fumes during built-up roofing asphalt (BURA) operations. Critical Reviews in Toxicology, 45(10), 873-918. doi:10.3109/10408444.2015.1094450

Roseen, R.M., T.V. Janeski, & J. Gunderson (2011). Case Studies Economic Benefits of LID Practices: Boulder Hills, New Hampshire. In Forging the Link: Linking the Economic Benefits of Low Impact Development and Community Decisions. University of New Hampshire Stormwater Center, Durham, N.H. pp. 3-4–3-8.

Sañudo-Fontaneda, L., Andres-Valeri, V., Costales-Campa, C., Cabezon-Jimenez, I., & Cadenas-Fernandez, F. (2018). The long-term hydrological performance of pervious pavement systems in northern spain: An approach to the “End-of-life” concept. Water, 10(4), 497. doi:10.3390/w10040497

Starke, P., Göbel, P., & Coldewey, W. G. (2010). Urban evaporation rates for water-permeable pavements. Water Science and Technology : A Journal of the International Association on Water Pollution Research, 62(5), 1161-1169. doi:10.2166/wst.2010.390

Stempihar, J.J., T. Pourshams-Manzouri, K.E. Kaloush, & M.C. Rodezno (2012). Porous Asphalt Pavement Temperature Effects for Urban Heat Island Analysis. Transportation Research Record: Journal of the Transportation Research Board, Vol. 2293, p. 123–130. DOI: 10.3141/2293-15

Tennis, P., M. L. Leming, and D. J. Akers. (2004). Pervious Concrete Pavements. Engineering Bulletin 302.02. Portland Cement Association, Skokie, IL, and National Ready Mixed Concrete Association, Silver Spring, MD.

Yang, Y., Endreny, T. A., & Nowak, D. J. (2015). Simulating the effect of flow path roughness to examine how green infrastructure restores urban runoff timing and magnitude. *Urban Forestry & Urban Greening, 14*(2), 361-367. doi:10.1016/j.ufug.2015.03.004

Zellner, M., Massey, D., Minor, E., & Gonzalez-Meler, M. (2016). Exploring the effects of green infrastructure placement on neighborhood-level flooding via spatially explicit simulations.

Computers, Environment and Urban Systems, 59, 116-128. doi:10.1016/j.compenvurbsys.2016.04.008

Zhao, J., Zhao, Y., Zhao, X., & Jiang, C. (2016). Agricultural runoff pollution control by a grassed swales coupled with wetland detention ponds system: A case study in taihu basin, china. *Environmental Science and Pollution Research, 23*(9), 9093-9104. doi:10.1007/s11356-016-6150-2

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Figure 2: Pervious concrete pavement cross section (adapted from EPA, 2010)	https://www.fhwa.dot.gov/pavement/concrete/pubs/hif13006/hif13006.pdf
Figure 3: Rain gardens cross section	https://parkslopeciviccouncil.org/wp-content/uploads/2013/01/Rain gardens.jpg
Figure 4: Example of rain gardens in New York City	https://www.mnn.com/earth-matters/climate-weather/blogs/meet-the-rain gardens-new-yorks-new-weapon-in-the-war-against-water
Figure 5: Typical pervious concrete properties	Tennis et al., 2004; Obla, 2007

APPENDIX A – Rainfall Infiltration Rates

According to NIWA (2018), during a 100-year rainstorm in Christchurch, 138mm of rain falls within 24 hours, which equates to 138L/m^2, or 0.138m^3 per square meter of land area. Typical permeable concrete infiltration rates fall between 81 to 734L/m^2 as shown in *figure 6* below (Tennis et al., 2004; Obla, 2007). It is recommended that this installation contains at least 1m^3 of engineered bed aggregate beneath the permeable concrete surface, containing 40% subsurface void volume within the gravel base.

Each square meter of this installation provides approximately 0.4m^3 water storage capacity. During the 100-year rainstorm outlined above, 0.138m^3 of water would enter this system in 24 hours. If a ratio of 3:1 impervious to SUDS coverage is implemented, the resulting 0.552m^3 (0.138m^3 + 0.414m^3 surrounding runoff volume) of rain water would enter the 0.4m^3 installation. Depending on the drainage capacity of the surrounding subsoil, flooding in this case may be minimal or completely avoided.

According to the standards set out by the New Zealand Building Code, Verification Methods and Acceptable Solutions uses the annual return interval of 10 years rather than 100. During a 10-year rainstorm, Christchurch receives 85L/m^2, or 0.085m^3 per square meter of land area. At a ratio of 3:1 SUDS incorporation, each 0.4 cubic meter installation would receive 0.34m^3 of water in 24 hours. Therefore, according to the NZBC E1, permeable pavements which include the recommended 1-meter subbase depth, are compliant with New Zealand Building Code, and qualify as an Alternative Method.

Property	Common Value / Range
Plastic Concrete	
Slump	N/A
Unit weight	70% of conventional concrete
Working time	1 hour
Hardened Concrete	
In-place density	100 to 125 lb/ft^3
Compressive strength	500 to 4,000 lbf/in^2 (typ. 2,500 lbf/in^2)
Flexural strength	150 to 550 lbf/in^2
Permeability	2 to 18 gal/ft^2/min (384 to 3,456 ft/day)

1 in = 25.4 mm; 1 lb/ft^3 = 16 kg/m^3; 1 lbf/in^2 = 6.89 kPa; 1 gal/ft^2/min = 40.8 L/m^2/min

Figure 5: typical pervious concrete properties (Tennis et al., 2004; Obla, 2007)

APPENDIX B – Mandatory Provision for Building Work in the New Zealand Building Code Clause E1 Surface Water

OBJECTIVE

E1.1 The objective of this provision is to:

(a) Safeguard people from injury or illness, and other property from damage, caused by surface water, and
(b) Protect the outfalls of drainage systems.

FUNCTIONAL REQUIREMENT

E1.2 *Buildings* and *sitework* shall be constructed in a way that protects people and *other property* from the adverse effects of *surface water*.

PERFORMANCE

E1.3.1 Except as otherwise required under the Resource Management Act 1991 for the protection of *other property*, surface water, resulting from an event having a 10% probability of occurring annually and which is collected or concentrated by buildings or sitework, shall be disposed of in a way that avoids the likelihood of damage or nuisance to other property.

E1.3.2 *Surface water*, resulting from an event having a 2% probability of occurring annually, shall not enter buildings.

E1.3.3 Drainage systems for the disposal of *surface water* shall be constructed to:

(a) Convey surface water to an appropriate outfall using gravity flow where possible,
(b) Avoid the likelihood of blockages,
(c) Avoid the likelihood of leakage, penetration by roots, or the entry of ground water where pipes or lined channels are used,
(d) Provide reasonable access for maintenance and clearing blockages,
(e) Avoid the likelihood of damage to any outfall, in a manner acceptable to the network utility operator, and
(f) Avoid the likelihood of damage from superimposed loads or normal ground movements.

APPENDIX C – Comparison Cost of Pervious and Conventional Concrete Installations in Christchurch

The following figures were obtained using pricing from local suppliers in the greater Christchurch area:

Pervious Concrete Residential Driveway 100m2	Price
Excavation Equipment	1,500
800mm pit run, base course	1,550
Pervious concrete	2,500
Disposal of excavation	1,600
Labour	4,000
Petrol	800
Total	**11,950**

Conventional Concrete Residential Driveway 100m2	Price
Contractor 1 Quote	10,700
Contractor 2 Quote	10,438
Contractor 3 Quote	10,036
Average Price	**10,391**
Premium for Pervious Concrete	**15%**

*Quotes from 3 contractors above does not include installation of drainage systems.

APPENDIX D – Firth Permeable Pavement Presentation

Images sourced from New Zealand Institute of Landscape Architects
https://nzila.co.nz/media/user/PDF's/Permeable%20pavements%20NZILA%20August%2017-reduced.pdf

ATTACHMENT A: Original Submission

31 August 2018

Consent Hearings
Environment Canterbury
PO Box 345
Christchurch 8140

Subject : Including Green Infrastructure in Stormwater Drainage Planning Mitigates Pluvial Flooding

To whom it may concern,

Recent studies confirm that if stormwater drainage plans were to require the use of Green Infrastructure (GI) installations, such as permeable concrete or rain gardens/rain gardens, flooding in heavy rainstorms may be prevented. This strategy is part of the emerging area of Sustainable Drainage Systems (SuDS), where GI installations encourage the infiltration and temporary storage of stormwater at a neighbourhood level. GI installations were studied in both the Chicago and Christchurch alluvial planes, which considered soil samples, current drainage systems, and flood flow annual probabilities, and it was estimated that incorporating 30% Green Infrastructure into impervious development mitigates pluvial flooding during a 100-year storm event. It should be noted that the marginal benefit of incorporating rain gardens in urban environments greatly decreases above 30% coverage (Zellner et al., 2016).

Rain gardens have not only shown positive results in mitigating flood hazards by reducing surface water runoff, but it provides tertiary benefits such as the support of native biodiversity, ecological and hydrological cycle restoration, non-point source pollution reduction, carbon sequestering, as well as improving the mental health of residents (Everett et al., 2016; Zhao et al., 2016). Incorporating pervious concrete and rain gardens is essential to mitigate flooding and pollution caused by large storm events in Christchurch. For further information, please refer to the summary of research on pages 2 through 7.

Therefore, in support of the Christchurch City Council consent application number **CRC190445**, I request that the consent authority make the following amendments:

32 Changes to the Proposed Draft Conditions – June 2016 document Section 3:
a. Specific guidelines for implementation of stormwater management within the catchment to achieve the following objectives:
i. Improve ecosystem health
ii. Improve water quality
iii. Maintain flood storage and flow capacity
iv. Enhance mana whenua values~~;~~
v. Support neighbourhood-scale extra-over detention Sustainable Drainage System methods, including permeable concrete and rain gardens;

33 To require Stormwater Management Plans (SMP), in their Implementation Plans, a minimum of 5% but optimally 30% surface area allocation to Green Infrastructure in urban environments. I believe that the minimum requirement may be reasonably achieved throughout central city Christchurch by the end of the Christchurch Long Term Plan in 2028.

Thank you for taking the time to review this submission.

Sincerely,

The effects of Green Infrastructure and Sustainable Drainage Systems design on flood mitigation

By Adrianna Hess

Background

One of the emerging strategies to mitigate flooding in urban environments is to use Green Infrastructure in the creation of Sustainable Drainage Systems (SuDS). SuDS are stormwater management installations that mimic natural hydrological processes, and often utilise vegetated land surfaces; they attenuate flood impacts by temporarily storing water, often filtering the pollutants at the source, and encouraging infiltration of stormwater into the ground (Hoang & Fenner, 2016). Traditional Grey Infrastructure on the other hand, refers to the conversion of pervious land (i.e., soil) and vegetated land parcels to impervious cover such as asphalt and concrete, which both stops infiltration and speeds up stormwater runoff, which leads to water quality pollution by flushing contaminants directly into waterways during storm events (Yang et al., 2015).

One specific type of Green Infrastructure system, rain gardens, which is shown in *Figure 1* below, has been simulated and analyzed by Zellner et al. (2016). This engineered piece of land collects rain through a cut in the curb, and allows street runoff to infiltrate through sandy soil, thereby being absorbed by the grasses and trees planted within before gradually filtering down into the groundwater table (Schulz, 2014). Green Infrastructure soils are typically engineered to contain between 85% and 88% sand for optimal infiltration (Zellner et al., 2016).

Figure 1: *Bioswale in New York City (Shulz, 2014)*

Rain gardens has not only shown positive results in mitigating flood hazards by reducing surface water runoff, but it provides tertiary benefits such as carbon sequestering, ecological and hydrological cycle restoration, non-point source pollution reduction, as well as improving the mental health of residents (Everett et al., 2016; Zhao et al., 2016). As civilization continues to rapidly urbanize, we must continually assess our best management practices and improve the way we interact with the natural environment; one way of reducing humans' negative impact on hydrological cycles, and thus ecosystems via intensified urbanization, appears to be the implementation of Green Infrastructure such as rain gardens and permeable pavement.

Both rain gardens (shown in *Figure 1* above) and permeable pavement (shown in *Figure 2* below*)* help to filter contaminants and excess nutrients from incoming stormwater before it discharges into waterways (Auckland Council, 2017; Boogaard et al., 2014). While the benefits of filtering contaminants and pollution may be obvious, the lesser-understood problem of excess nutrients can become a health hazard to local residents. When fertilizing agents are washed directly into local water bodies via drainage pipes, they accumulate and cause the rapid growth of toxic algae

(Zhao et al., 2016). When this toxic algae occurs where cities obtain drinking water, the results can kill unsuspecting residents, and leave millions of others without drinking water for a week or more (Qin et al., 2010).

Figure 2: *Permeable pavement demonstration (Harrison, 2011)*

Context to Christchurch

Self-proclaimed as the Garden City, Christchurch endeavors to establish green spaces in every possible location, from derelict lots to neighborhood parks (Harvie, 2016). Christchurch also has a history of stormwater infrastructure damage, including pipe shearing and sewage contamination after major earthquakes (Giovinazzi et al., 2011). Due to the vulnerability of Grey Infrastructure to earthquakes, implementing Green Infrastructure in SuDS designs (such as rain gardens or permeable pavement) may prevent earthquake hazards from disrupting stormwater drainage in the future.

The Landscape Green Infrastructure Design (L-GrID) model, which is discussed below, was based on a neighborhood from Chicago Illinois that is almost identical to Christchurch; this neighbourhood experiences similar rainfall events, has comparable water table elevation, and the same silty loamy soil composition as the alluvial plain upon which Christchurch was established (Morrow et al., 1991; Wilson, 2006). Therefore, at this moment, the findings from the L-GrID model study may be applied directly to Christchurch in a general sense; Christchurch could indeed benefit from implementing a Green Infrastructure trial program if both effective placement strategy and coverage ratios of 10% to 30% are utilised. If Christchurch were to observe the flood mitigation effects of Green Infrastructure, it would be possible to modify existing best management practices to include Green Infrastructure as a part of the SuDS strategy in city planning.

Summary of Research

Zellner et al. (2016) have stated that if Green Infrastructure is to be required by law, more information on patterns of implementation are needed. There has been little examination of how Green Infrastructure interacts with the other components of the hydrological system, including roads and sewers, and their collective impact on stormwater hydrology (Zellner et al., 2016). In response to these problems, the Landscape Green Infrastructure Design (L-GrID) model (shown in *Figure* 3) was created to illustrate a typical urban neighborhood composed of $10m^2$ pixels, which depicts either impervious or pervious ground. This model also takes into account existing stormwater runoff,

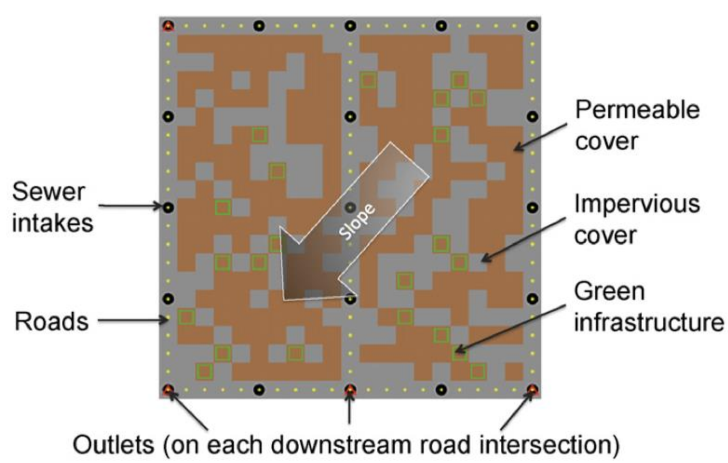

Figure 3: *Landscape features of L-GrID (Zellner et al., 2016)*

and a northeast to southwest elevation slope. This 4km^2 simulated neighborhood considers the magnitude of storm events, and shows that with as little as 10% coverage, Green Infrastructure can greatly contribute to runoff capture in small storms, but it would need to be doubled or tripled to deal with larger storms in a similar way (Zellner et al., 2016).

Before running storm simulations, six different rain gardens placement designs were created in order to compare drainage effectiveness. As shown in *Figure 4* below, these scenarios were tested using three different strategies, including random placement, proximity to roads, and elevation.

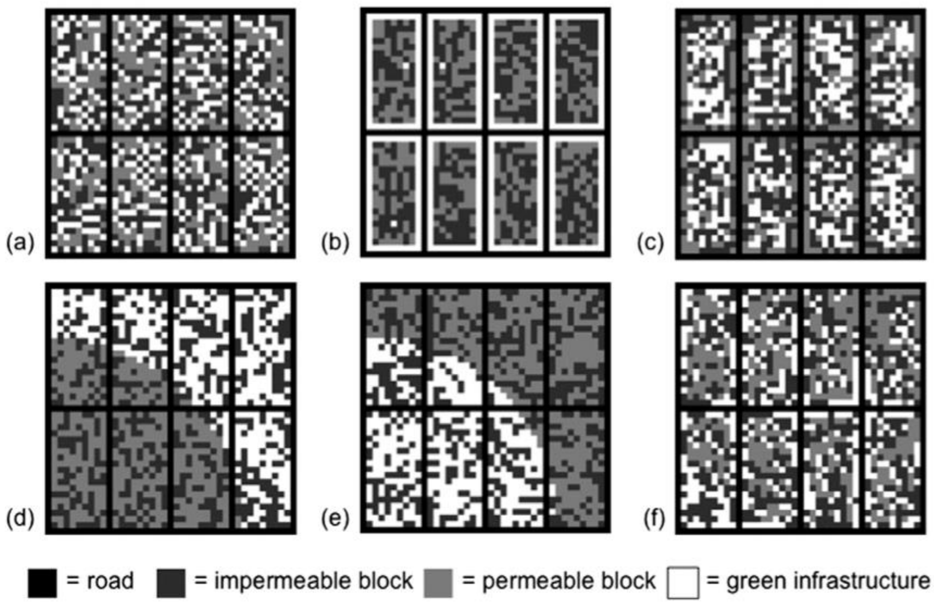

Figure 4: *Green infrastructure placement scenarios: (a) sorted random baseline, (b) adjacent to roads, (c) away from roads, (d) upstream, (e) downstream, and (f) hybrid (Zellner et al. 2016)*

After test runs were conducted for 24-hour storm events of 5- and 100-year magnitude, Zellner et al. (2016) found that the strategy based on proximity (b) adjacent to roads had the most effective infiltration, whereas placement based on elevation, both (d) upstream or (e) downstream, were equally ineffective. For 5-year storm events (84.5mm in 24 hours)$^+$, just 10% rain gardens coverage prevented neighborhood flooding, but for 100-year rain events (178.4mm in 24 hours)$^+$, 30% incorporation is required to prevent neighborhood flooding. It should be noted that the marginal benefit of incorporating rain gardens in urban environments greatly decreases above 30% coverage (Zellner et al., 2016).

Links to other research

As this paper is fairly new, it has been cited only three times in other research. The first article recognizes that traditional drainage approaches using Grey Infrastructure offer low adaptation to urban growth and climate change, and suggests retrofitting urban drainage systems with Green Infrastructure (Alves et al., 2016). The second article not only recognizes Green Infrastructure for its importance to ecological communities, but it suggests that the amenities resulting from Green Infrastructure are enjoyed primarily by communities of higher socio-economic status; the author suggests that Environmental Justice needs to be served to all communities, as decisions provisioning ecosystem services in urban areas often neglect economically, socially, or racially disadvantageous communities (Marshall & Gonzalez-Meler, 2016). The last paper asserts that biodiversity-led Green Infrastructure systems provide resilience to cities by mitigating overheating, flooding and air pollution, creating ecosystem services to stop biodiversity loss, and supporting the health and wellbeing of residents (Connop et al., 2016).

It’s exciting to see that the scientific community is compiling research that supports this paradigm shift in urban design to incorporate Green Infrastructure. This research also starts a discussion about how to reach all communities regardless of socioeconomic status when implementing Green Infrastructure, because these amenities have a direct and positive impact on the health, well-being, and the quality of life of urban communities (Marshall et al., 2016). However, the application of Green Infrastructure remains a key challenge to public authorities and developers, because the application-oriented frameworks required in mainstreaming Green Infrastructure are still lacking (Connop et al., 2016). Therefore, Green Infrastructure initiatives may be most effectively implemented and observed at a City or District Council level before national governments take notice of the benefits to be derived.

+Rainfall quantities calculated using the High Intensity Rainfall Design System Calculator Version 3 (NIWA, 2017).

Critical Analysis of Methods

Green Infrastructure used as a drainage function of sustainable cities is a relatively new concept, having emerged at the end of the 1980's (Lieberherr-Gardiol, 2008). The L-GrID modeling tool was designed to be an inexpensive and accessible tool, which allows urban planners to explore how Green Infrastructure impacts flooded area and runoff volume (Zellner et al., 2016). The major disadvantage of this model is that it is not an empirical test; all results from this particular journal are merely calculated presumption. However, this disadvantage cannot be mitigated due to the impossibility of constructing a $4km^2$ model neighborhood inside of a laboratory. Therefore, L-GrID may be used in conjunction with other existing studies to more precisely quantify observed infiltration rates. Tools such as L-GrID are needed to inform the development of planning and regulatory recommendations for stormwater management with an understanding of how Green Infrastructure may work (or not) in a variety of situations (Zellner et al., 2016).

Recommendations

To fill the research gap regarding an understanding of how Green Infrastructure works in certain situations, a project that implements and assesses SuDS is in order. If one could establish a flood risk analysis for a particular neighbourhood, including historical data correlating rain events with resulting flood levels, it would be possible to (a) predict efficient flood mitigation strategies using the L-GrID model, (b) implement SuDS and assess the accuracy of the models' predictions with empirical observation, and (c) make well-informed recommendations to policy makers. After reading through general discussions on Green Infrastructure, it appears that the major barrier to implementing this technology is an inability to accurately create a cost-benefit analysis. Potentially, cities could save money by avoiding flooded property damage using rain gardens or permeable pavement, but several ongoing costs may be necessary, e.g. semiannual maintenance of these installations to keep them working efficiently.

Conclusion

Beyond flood mitigation, Green Infrastructure as a part of the SuDS strategy contributes to local community health savings and ecosystem services (Harvie, 2016). While the field of Green Infrastructure implementation is fairly new (Lieberherr-Gardiol, 2008), the results of recent studies are very promising regarding a paradigm shift from Grey Infrastructure to a resilient Green Infrastructure model (Zellner et al., 2016). If cities wish to be more resilient, mitigate flooding, as well as prevent non-point source pollution and the resulting degradation of community water supplies, we must act quickly to require the implementation of Green Infrastructure systems in city planning.

References

Alves, A., Sanchez, A., Vojinovic, Z., Seyoum, S., Babel, M., & Brdjanovic, D. (2016). Evolutionary and holistic assessment of green-grey infrastructure for CSO reduction. *Water,8*(9), 402. doi:10.3390/w8090402

Auckland Council (2017). Swales and Filter Strips Construction Guide. *Stormwater Device Information Series.* Retrieved from http://www.aucklandcouncil.govt.nz/EN/environmentwaste/stormwater/Documents/swaleconstructionguide.pdf

Boogaard, F., Lucke, T., & Beecham, S. (2014). Effect of age of permeable pavements on their infiltration function. *CLEAN – Soil, Air, Water, 42*(2), 146-152. 10.1002/clen.201300113

Connop, S., Vandergert, P., Eisenberg, B., Collier, M. J., Nash, C., Clough, J., & Newport, D. (2016). Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. *Environmental Science & Policy, 62*, 99-111. doi:10.1016/j.envsci.2016.01.013

Everett, G., Lamond, J., Morzillo, A. T., Chan, F. K. S., & Matsler, A. M. (2016). Sustainable drainage systems: Helping people live with water. *Proceedings of the Institution of Civil Engineers - Water Management, 169*(2), 94-104. doi:10.1680/wama.14.00076

Giovinazzi, S., Wilson, T. M., Davis, C., Bristow, D., Gallagher, M., Schofield, A., Villemure, M., Eidinger, J., & Tang, A. (2011). Lifelines performance and management following the 22 February 2011 Christchurch earthquake, New Zealand: Highlights of resilience.

Harrison, J. (2011). Permeable pavement demonstration. *Wikipedia.* Retrieved from https://en.wikipedia.org/wiki/Permeable_paving#/media/File:Permeable_paver_demonstration.jpg

Harvie, W. (2016). A Great Place to Be: Christchurch locals still want a clean, green garden city. *The Press.* Retrieved from http://www.stuff.co.nz/the-press/christchurch-life/a-great-place-to-be/77229364/christchurch-wants-to-be-a-clean-green-garden-city

Hoang, L., & Fenner, R. A. (2016). System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal, 13*(7), 739-758. doi:10.1080/1573062X.2015.1036083

Lieberherr-Gardiol, F. (2008). Urban sustainability and governance: Issues for the twenty-first century. *International Social Science Journal, 59*(193-194), 331-342. doi:10.1111/j.1468-2451.2009.01670.x

Morrow, William S., Sharpe, & Jennifer B. (2009). Preliminary Assessment of the Potential for Inducing Stormwater Infiltration in Cook County, Illinois. *U. S. Geological Survey, U. S. Department of the Interior,* https://pubs.usgs.gov/of/2009/1212/pdf/ofr2009-1212.pdf (accessed 7 March 2017)

Marshall, K. A., & Gonzalez-Meler, M. A. (2016). Can ecosystem services be part of the solution to environmental justice? *Ecosystem Services, 22*, 202-203. doi:10.1016/j.ecoser.2016.10.008

Nie, L. (2016). Enhancing urban flood resilience – a case study for policy implementation. *Proceedings of the Institution of Civil Engineers - Water Management, 169*(2), 85-93. doi:10.1680/wama.14.00079

NIWA. (2017). High Intensity Rainfall Design System Calculator Version 3. *National Institute of Water and Atmospheric Research.* https://hirds.niwa.co.nz/

Qin, B., Zhu, G., Gao, G., Zhang, Y., Li, W., Paerl, H.W., & Carmichael W.W. (2010). A drinking water crisis in Lake Taihu, China: linkage to climatic variability and lake management. *Environ Manage*, 45(1), 105-12. doi:10.1007/s00267-009-9393-6

Shulz, D. (2014). 2,000 More Rain gardenss Will Help NYC Absorb Stormwater. *6SQFT.* Retrieved from https://www.6sqft.com/2000-more-rain gardenss-will-help-nyc-absorb-stormwater/

Webb, T. H., Smith, S. M., & Trangmar, B. B. (1991). Land Resource Evaluation of Christchurch City. *N.Z. Department of Scientific and Industrial Research DSIR Land Resources: A Contract Report to Canterbury Regional Council and Christchurch City Council.* Retrieved from: https://lris.scinfo.org.nz/document/440-land-resources-evaluation-of-christchurch-city/

Wilson, John. (14 Sep 2006). Canterbury region - Weather and climate reviewed & revised 6 Jul 2015. *Te Ara - the Encyclopedia of New Zealand,* Retrieved from http://www.TeAra.govt.nz/en/canterbury-region/page-4

Yang, Y., Endreny, T. A., & Nowak, D. J. (2015). Simulating the effect of flow path roughness to examine how green infrastructure restores urban runoff timing and magnitude. *Urban Forestry & Urban Greening, 14*(2), 361-367. doi:10.1016/j.ufug.2015.03.004

Zellner, M., Massey, D., Minor, E., & Gonzalez-Meler, M. (2016). Exploring the effects of green infrastructure placement on neighborhood-level flooding via spatially explicit simulations. *Computers, Environment and Urban Systems, 59*, 116-128. doi:10.1016/j.compenvurbsys.2016.04.008

Zhao, J., Zhao, Y., Zhao, X., & Jiang, C. (2016). Agricultural runoff pollution control by a grassed swales coupled with wetland detention ponds system: A case study in taihu basin, china. *Environmental Science and Pollution Research, 23*(9), 9093-9104. doi:10.1007/s11356-016-6150-2