Impacts of Innovative WSUD Intervention Strategies on Infrastructure Deterioration and Evolving Urban Form

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Abstract

It is not widely appreciated how innovative Water Sensitive Urban Design (WSUD) intervention strategies can assist in countering the negative effects of deteriorating water infrastructure and evolving urban areas. Deteriorating infrastructure is a problem for the majority of urban centres around Australia and is becoming more important as assets age, populations increase and urban centres expand. These problems generally result in diminishing asset performance and serviceability. This paper provides a discussion of infrastructure deterioration, including some of the specific physical causes of deterioration, and also contrasts current infrastructure practice with innovative WSUD approaches to mitigate the impacts of infrastructure deterioration.

A simple case study is presented to demonstrate how traditional infrastructure can be augmented with innovative WSUD approaches to provide significant improvements in the performance of traditional water infrastructure. The computer program PURRS has been used to simulate the effects of water demand management, wastewater reuse and rainwater tanks on mains water supply. This has been done by modelling the lot scale water balance and then determining the water supply characteristics. A discussion on the potential benefits that may be obtained from the combined water cycle asset serviceability is provided which describes how lifecycle costs may be reduced and asset replacements deferred. This paper concludes that it is absolutely necessary to investigate the urban water cycle in a holistic and integrated way in order to provide more optimal outcomes to urban water cycle problems.

Introduction

In addition to the currently severe drought being experienced across much of Australia, much of Australia's water infrastructure is considerably aged, and services provided by those assets are diminished. Present water supply shortages further exacerbate the problem because it is difficult to efficiently use water with inefficient infrastructure. The deterioration of water assets is often exponential in nature and solutions will only become more difficult to achieve as time passes and the impacts of deterioration become increasingly serious and complex. These impacts are magnified by population growth that increases demands on water sources and the performance of infrastructure.

As part of the water reform process underway in Australia, it is essential to manage current and emerging water problems as part of an integrated water cycle. This research program aims to investigate innovative WSUD strategies to counter deteriorating infrastructure, with the dual aims of providing options for decision makers while enhancing ecosystem health. The complex and integrated nature of the problem is realised when attempting to include the effects of human behaviour, water demand and system performance requirements of water infrastructure, all within an evolving urban landscape.

In the past, infrastructure replacement, rehabilitation and upgrades have been tackled primarily by repairing failures rather than intervening in a timely manner to maintain service levels. This has happened due to limited knowledge and prediction capabilities of the infrastructure's condition and performance, and is further limited by availability of funds. This approach does not ultimately resolve problems but defers consequences to a later date. Solutions are also partially prevented by the lack of systems approach or analysis of performance tradeoffs that can provide optimum strategies. This research program will take a systems approach to the problem of deteriorating water infrastructure and explore innovative solutions to urban water cycle serviceability issues.

This research program is investigating a combined approach that utilises traditional and WSUD infrastructure strategies. Some of the objectives of the research program are to demonstrate that timely WSUD intervention can provide the solutions to urban water cycle serviceability issues as shown in Figures 1 and 2. Figure 1 shows that asset serviceability may be improved with timely WSUD intervention. All water infrastructure assets have a life span and will deteriorate with age. With this deterioration comes a decrease in serviceability, as conduits lose hydraulic efficiency, become increasingly leaky, and become more costly to maintain. Timely WSUD intervention can improve the combined asset serviceability by reducing, for example with the addition of rainwater tanks, the flow volumes through a system, which in turn reduces the volume of water lost through leakage thereby conserving water, reducing water treatment and pumping costs. This approach can avoid the high cost of replacing buried infrastructure (pipes) in urban areas.

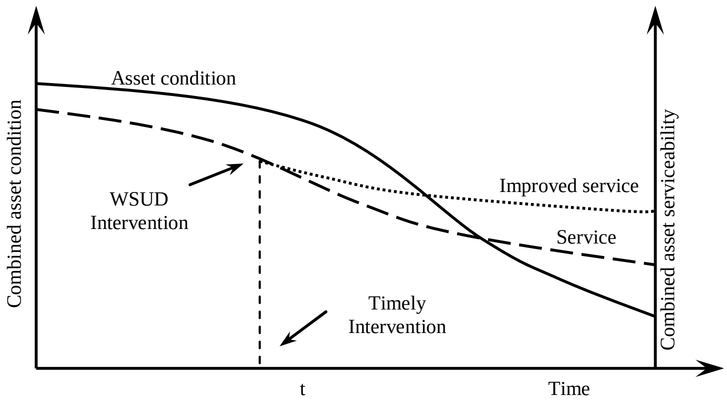

Figure 1: Asset condition and serviceability, with WSUD intervention, as a function of time.

Figure 2 shows that after an initial capital outlay for some type of timely WSUD intervention, lifecycle costs of the existing urban water infrastructure may reduce over time. This is in stark contrast to the ever increasing costs associated with deteriorating traditional water infrastructure. Figure 2 also shows that ecosystems may respond positively to timely WSUD intervention resulting in greater biodiversity and improved ecosystem health, for example, by returning more natural flow conditions or increasing diversity of habitat.

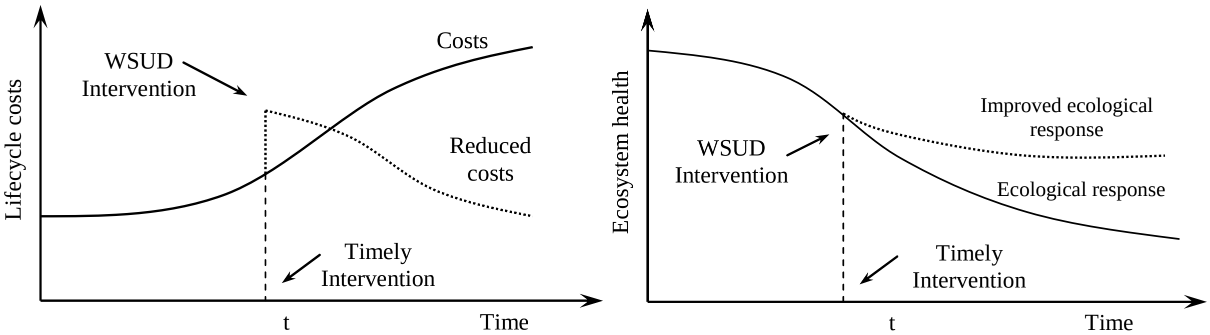

Figure 2: Infrastructure costs and ecosystem response with WSUD intervention.

In addition to what Figures 1 and 2 describe, innovative WSUD intervention can play a potentially important role in countering uncertainty in water related to drought and climate variability generally. Urban landscapes are also constantly changing with urban renewal and expansion a natural part of city development. This evolving urban form presents itself as a "moving target" for urban water solutions, and is an additional layer of uncertainty. The evolving urban form includes changing population densities which will impact on infrastructure performance and provision, and may potentially change ecosystem response.

Appropriate WSUD intervention is an opportunity to build resilience and flexibility into the water system to prepare for future challenges.

The Problem

Water infrastructure in Australia can be broadly grouped into providing three services, these being stormwater drainage, water supply and distribution, and wastewater collection and disposal. The typical range of assets includes pipes, channels, pumps, treatment plants and related equipment, retention basins and service reservoirs, and large supply dams. The performance of water infrastructure has been rated as only adequate to poor (Engineers Australia, 2001) and it is known there has been massive underinvestment in water infrastructure of many billions of dollars. An estimated investment shortfall of $50 billion has been reported by Engineers Australia (2006); various parliamentary inquiries suggest even greater costs. Extensive upgrading, rehabilitation or replacement is required over the coming years to maintain existing service levels. However, resources available to make improvements to infrastructure is limited, and decision makers must prioritise replacement and rehabilitation needs.

Deterioration is usually referred to as the process whereby water assets undergo a gradual reduction in performance, often directly related to the age of the asset. This deterioration, however, can be accelerated under certain circumstances, such as when a conduit is more heavily utilised than design values, under certain environmental conditions, and due to structural changes or failures.

Water conduit infrastructure has different modes of deterioration depending on the type of conduit (e.g. open or closed, water supply or sewage disposal) and conduit construction material (e.g. concrete, iron or plastics). These modes of deterioration can be broadly grouped as either deterioration of the conduit internal surface, structural deterioration, and general obstructions to flow. This can take place through leaching processes (Warner *et al.*, 1998), abrasion and roughening by water containing fine particles and solids (Andrewartha *et al.*, 2006), biological fouling (Minkus, 1954; Picologlou *et al.*, 1980; Barton *et al.*, 2004), and corrosion processes (DeSilva *et al.*, 2006). Deterioration by structural changes include crushing or collapse or vertical displacement, changes in pipe longitudinal slopes (Micevski *et al.*, 2002), and excessive water hammer and pressure effects. General obstructions to flow may include sedimentation of particles carried by the flow, physical obstruction or partial blockage by the collection of debris carried by the flow (particularly for stormwater and wastewater systems), and physical intrusion into the water conduit by tree roots (Coombes *et al.*, 2002).

Perhaps the most important consequence of conduit aging or deterioration is the formation of cracks and fractures which allows the infiltration and exfiltration of water. This is particularly significant for sewerage systems where wastewater may leak into the surrounding environment and for water supply systems where the loss of water requires an increase in flows to meet end user demands. Indeed water losses in a water supply pipe can account for a large percentage of the overall water demand of a system. Losses are directly proportional to the end of pipe demand, and so in effect, a reduction in human demand will also result in less “lost” water through leaks.

Infrastructure deterioration directly affects the economic return of an asset and decreases expected service levels. Accelerated deterioration affects the cost-benefits or payoff periods by reducing the life span of the asset. Shortened life spans of infrastructure complicate maintenance and replacement programs bringing forward replacement timeframes, which are usually not included in budget estimates. Innovative WSUD intervention strategies have the potential to significantly reduce long term infrastructure costs.

Traditional and Innovative WSUD Approaches to Infrastructure

Ultimately, WSUD strategies must be included in infrastructure best practice planning, design and management for all elements of the urban water cycle. Available WSUD approaches are only limited to the imagination and WSUD technologies are continually being developed. Innovative solutions are those other than traditional approaches, incorporating a systems approach, and one that is able to combine infrastructure types to provide a fully integrated infrastructure solution. Table 1 shows traditional and WSUD approaches that may be used to provide water services.

Table 1: Traditional versus WSUD approaches for typical infrastructure solutions.

Function	Traditional Approach and Technologies	WSUD Approach and Technologies
Flooding	Centralised discharge. Designed to mitigate minor flood risk. Based around rapid discharge of water, and hydraulically efficient systems. May includes the use of pipes, channels and storage basins.	Distributed management solutions with an array of available measures. May include the use of rainwater tanks, natural channels, bioretention systems, retention basins and ponds.
Water supply	Centralised supply and water treatment. May include supply reservoirs, pipes, treatment plants and pumps.	Integrated water management with multiple water sources. Incorporates fit for purpose use and a combination of centralised and decentralised infrastructure. May include the supplementation mains use with roof water, fit for purpose wastewater reuse and reduced water demand.
Wastewater	Centralised infrastructure for collection, treatment and discharge. Includes collection pipes and drainage to treatment plant.	Reduced wastewater discharge, and decentralised treatment opportunities. May include reduced water demand, fit for purpose wastewater reuse and small scale treatment options.
Water Quality Improvement	Driven mostly by aesthetics. Out of sight out of mind solutions. Limited mostly to wastewater via engineered treatment plants, outfalls, and diffusers. Stormwater discharges may be treated via gross pollutant traps at most or is simply not done.	Aimed at protecting downstream environments. Consists of distributed solutions and treatment train methods. May include such technologies as grass swales, infiltration trenches, bioretention systems, constructed wetlands.
Ecosystems	Usually not considered. Some simplistic approaches such as dissolved oxygen sag downstream of discharges.	Based around maintenance and improvement of ecosystem health and social aspects such as local amenity. Includes provision of habitat, maximising biodiversity and resource conservation.
Objectives	Maintenance of high public health. Provide low cost options. Centralisation of risk.	Maintenance of high public health. Provide low cost options. Ensure water security. Enhance ecosystem health. Consider infrastructure lifecycles and energy use.

Traditional methods are usually one-dimensional and linear in their approach (e.g. one pass infrastructure) and methods to achieve solutions are fragmented, precluding integrated outcomes. An additional consequence of the traditional approach is that it is difficult to assess the success of the designs and outcomes for the full range of issues surrounding the provision of water infrastructure.

Innovative WSUD approaches are by philosophy multi-dimensional, integrated, include methods to describe objectives, take a whole of system approach, and are organised in the way objectives can be achieved. Most design and consulting professionals use commercial software to investigate and design water infrastructure which does not include the ability to concurrently design for, say, flooding and water quality objectives. A range of different but dependent tasks are usually completed in a piece-meal approach.

In any event, the traditional approach to deteriorating infrastructure is an inflexible one. There must be a break in the cycle of replacing like with like, and this starts with the incorporation of the principles of WSUD in finding new solutions to infrastructure issues. This new approach should recognise that augmentation strategies are available to alleviate problems encountered with the traditional approaches to water infrastructure.

Simple Case Study

A simple case study is presented here to show how innovative WSUD strategies can change mains water use with significant positive changes propagating through the connected urban water cycle, demonstrating the integrated nature of the urban water cycle. Different WSUD interventions have been modelled at the allotment scale using PURRS (version 7.2, Coombes, 2004). The scenarios modelled include one with no intervention described as Business As Usual (BAU), another with water efficient appliances as a form of mains water demand management (DM), another with the use of a rainwater tank to supplement mains water use (RW), and the last with fit for purpose wastewater reuse to supplement mains water use (WW).

The performance of a household with 3 occupants in the Sydney region was continuously simulated over a period of 89 years using PURRS. Long term average annual rainfall over the simulation period was 1,204 mm. The RW scenario consisted of a 3 kL rainwater tanks collecting rainfall runoff from a roof area of 100 m used to supply laundry, toilet and outdoor water uses. The DM scenario included the use of a water efficient washing machine, toilets and shower heads. The DM+RW+WW scenario included use of rainwater for laundry and hot water purposes and use of treated wastewater for outdoor and toilet uses.

Figure 3 shows the lot scale water balance with the different WSUD interventions. The different intervention strategies will have significant consequences on the provision of water services to that lot and the connected infrastructure. With increasing levels of intervention, greater reductions in mains water use (and associated leakage) can be made. All of the intervention scenarios provide reductions in mains water use, with the DM+RW+WW scenario providing the most dramatic reduction.

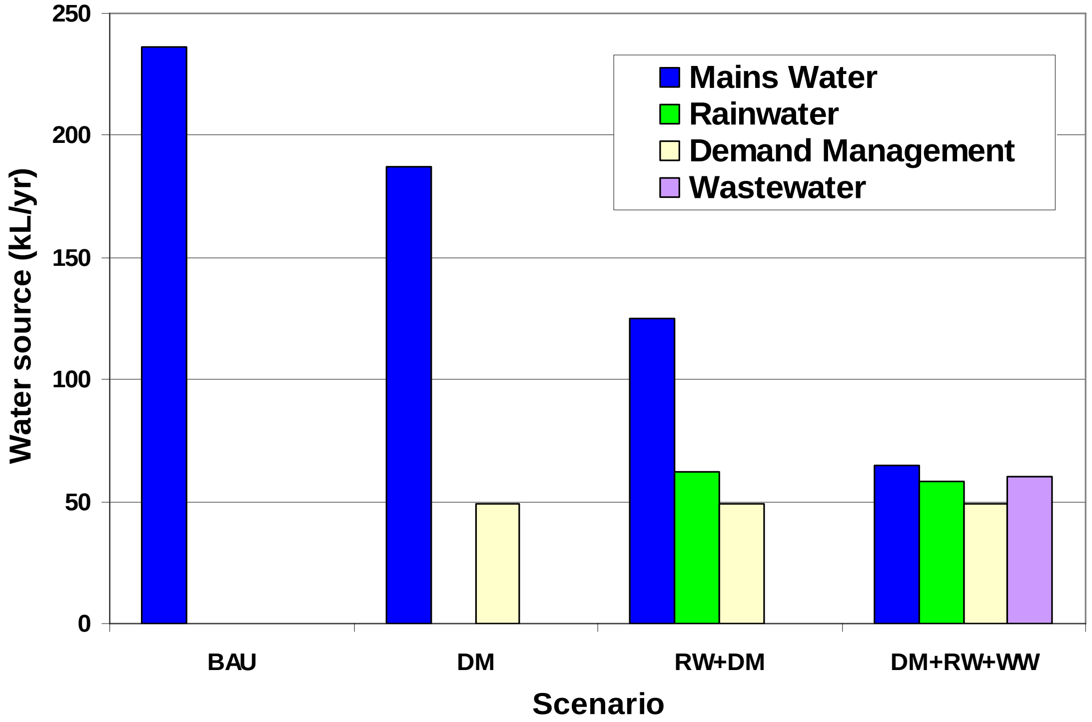

Figure 3: Water balances for different WSUD interventions in the Sydney region.

The WSUD intervention has not just reduced the total mains water demand (which on its own has considerable benefits), but has also changed the way (frequency distribution) in which the mains water is used. This change in water demand character at the lot scale has major consequences for locally connected infrastructure. Figure 4 presents the frequency distributions for the mains water demand for each of the WSUD intervention scenarios.

With the introduction of demand management there is a reduction (shift to the left) in daily water demand. There are also some small changes in the character of the water demand peaks. If rainwater is used to supplement the total water demand (in addition to DM), there is a greater reduction in mains water use, and also a significant change in the character of the peaks. There is now a greater frequency of mains water demand below 0.5 kL per day. If there is wastewater reuse (greywater for example to flush toilets or outdoor garden use) a further change is apparent with daily mains water use dramatically reduced, and also constrained at around 0.5-0.6 kL per day.

The effect of a change in daily water demand has profound impacts on the upstream water supply infrastructure. If the lot scale changes are propagated upstream, the result will be that serviceability of pipes will increase, as there is less demand, particularly during peak flow periods. There will be less demand on pumps to move the water, resulting in different energy use and maintenance profiles, and considerable economic saving. Service reservoir performance will be different having not to be filled as quickly, and draw down being slower. The water treatment plants will also be affected as there will be different requirements for chemical use (e.g. coagulants/flocculants and disinfection), energy use, and flow capacities. There will be considerable water savings, resulting in greater water security and different risk profiles for existing storage reservoirs and rainfall catchments. Finally, there will be different ecological impacts from where water is extracted, for example from a river or groundwater system.

There will also be associated changes to the wastewater infrastructure due to changed water demand. Consider the infrastructure in place for wastewater, where collection and discharge pipe serviceability will increase as there will be reduced flow volumes into the system, and importantly reduced peak flows. Wet wells or other buffer systems will provide greater safety against sewer surcharging and overflows to surrounding environments. Pumps will not have to work as hard, changing energy use profiles and reducing operation and maintenance costs. Rising mains will be more serviceable. Wastewater treatment plant operation and maintenance costs will reduce commensurate with the changes in chemical use, energy consumption, and biosolids production. Importantly, the downstream effects on ecosystems will be changed due to reductions in effluent discharges.

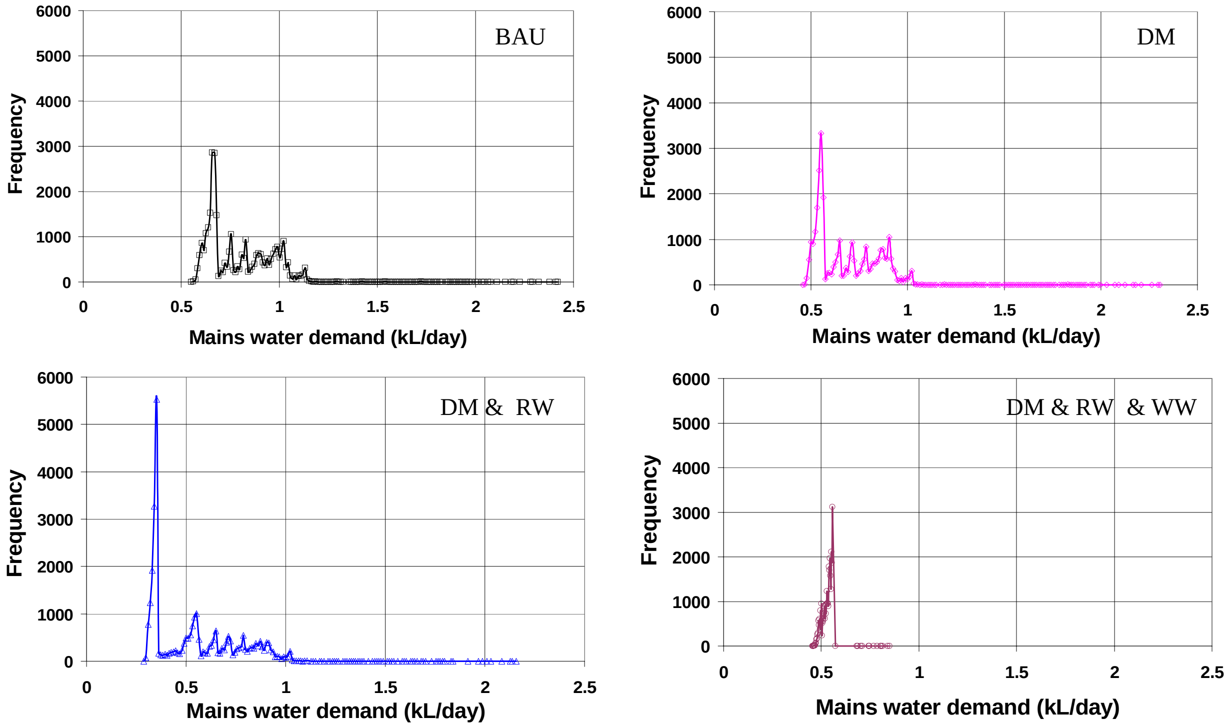

Figure 4: Changes in frequency distributions of total water demand with different WSUD intervention strategies.

Current industry practice for the design of water supply and sewerage systems are to use average water consumption data based on domestic, commercial or industry use. This data is mostly based on large area averages, and may be reasonable on the face of it, but there is no regard to local socioeconomic factors (or other factors) for likely water demand, potential impacts on connected ecosystems, and little regard to the serviceability of existing deteriorated infrastructure. The limitations of the traditional approach are further evident as systems age, infrastructure deteriorates, population densities increase and connections and demands from the system change. This type of design solution is currently used because there is currently little understanding of the complexities of water demand. Current design is based on largely empirical data with little theoretical or scientific understanding.

To reach more optimal infrastructure solutions there needs to be consideration of the likely integrated infrastructure design objectives. What is required of the infrastructure in terms of service? Is it unrealistic to design infrastructure to accommodate maximum flow events, which may occur just once during the day? Instead, should we consider meeting 95% or 90% of water demand and flow events? Table 2 presents values for 90 and 95 percentiles, averages, maximums and minimums for each of the intervention scenarios shown in Figure 4. It is shown that with additional WSUD interventions, there is less variance between statistics, and notably, dramatically reduced maximum values which will provide more certain risk profiles.

Table 2: Statistics for the water demand frequency distributions in kL/day.

Statistic	BAU	DM	DM & RWT	DM & RWT & WW
95th percentile	1.04	0.93	0.91	0.56
90th percentile	1.03	0.90	0.86	0.55
Average	0.79	0.68	0.54	0.53
Maximum	2.45	2.34	2.17	0.90
Minimum	0.55	0.43	0.29	0.46

Observations

WSUD can bring about positive changes to the water balance, water quality, water security and ecological health. In urban environments, the key question is how to best integrate WSUD into the infrastructure solution matrix to achieve these outcomes. This requires innovation and to be most effective, identification of optimal intervention timeframes.

This paper has briefly shown that issues such as the appropriate use of peak factors in the design of water infrastructure, and how the flow frequencies or water use characteristics may change with different WSUD intervention strategies and will be central to the present research program. How changes in the water balance affects connected infrastructure will be investigated by exploring the use of innovative WSUD strategies on infrastructure performance, and looking at the different infrastructure responses. Limited methods are currently available to design the integrated infrastructure systems that will necessarily include decentralised and more sophisticated water infrastructure solutions. The simple lot scale case study presented has illustrated the need for a systems approach to infrastructure design to obtain more optimal outcomes for the entire urban water cycle.

There are considerable hidden benefits that can be revealed to owners and operators of water infrastructure assets. Solutions can be found which enable a cost effective means of countering the negative impacts of deterioration and population growth with associated reductions in serviceability. As part of a holistic research approach, lifecycle costs, energy costs, likely ecosystem responses and other important objectives will be included as a systems analysis. How to feedback new information into the solution process will also be explored, as it is believed that more optimal solutions can be achieved if feedback loops can be better integrated into the various design and implementation stages of integrated water cycle systems.

Acknowledgements

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