The Urban Stormwater Farm

L'exploitation des eaux pluviales urbaines

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RÉSUMÉ

Plus de trois milliards de personnes peuplent actuellement les zones urbaines. Une augmentation de trois milliards supplémentaires est prévue d'ici 2050. L'augmentation des prix du pétrole, la quantité imprévisible de précipitations et les catastrophes naturelles sont autant de facteurs contribuant à la hausse des prix des produits alimentaires dans le monde. Pour un grand nombre de pays, la sécurité alimentaire est de plus en plus problématique. On constate aussi une conscience accrue des kilomètres alimentaires et de la notion d'eau virtuelle. Ces concepts désignent la quantité d'énergie et d'eau utilisée par la nourriture et autres biens de consommation. On a largement démontré que les agglomérations grandissantes sont de grandes consommatrices d'énergie et d'eau, et qu'elles produisent des quantités nuisibles d'eaux usées et favorisent le ruissellement des eaux de pluie en créant d'importantes zones imperméables. Dans cet article nous proposons un moyen efficace pour aborder à la fois les problèmes de sécurité alimentaire, les émissions de carbone et la pollution des eaux pluviales. Au moyen d'une étude de cas, nous démontrons par quel moyen il est possible de récolter et conserver l'eau de pluie des zones urbaines densément peuplées et la réutiliser pour produire des aliments à des prix relativement bas. De cette manière, il est possible de réduire les kilomètres alimentaires (émissions de carbone) et la consommation d'eau virtuelle, tout en tenant compte de la nécessité d'aménager durablement le territoire.

ABSTRACT

Currently more than 3 billion people live in urban areas. The urban population is predicted to increase by a further 3 billion by 2050. Rising oil prices, unreliable rainfall and natural disasters have all contributed to a rise in global food prices. Food security is becoming an increasingly important issue for many nations. There is also a growing awareness of both “food miles” and “virtual water”. Food miles and virtual water are concepts that describe the amount of embodied energy and water that is inherent in the food and other goods we consume. Growing urban agglomerations have been widely shown to consume vast quantities of energy and water whilst emitting harmful quantities of wastewater and stormwater runoff through the creation of massive impervious areas. In this paper it is proposed that there is an efficient way of simultaneously addressing the problems of food security, carbon emissions and stormwater pollution. Through a case study we demonstrate how it is possible to harvest and store stormwater from densely populated urban areas and use it to produce food at relatively low costs. This reduces food miles (carbon emissions) and virtual water consumption and serves to highlight the need for more sustainable land-use planning.

KEYWORDS

Urban, food security, stormwater harvesting, food miles, virtual water, sustainable land-use

1 INTRODUCTION

The world's total population is predicted to increase to 9 billion by 2050 and this will largely occur in dense, urban agglomerations (UN DESA, 2008). If current land use and consumption patterns continue this will result in:

- Significantly increased impervious areas draining to receiving waters
- Significantly increased volumes of stormwater runoff contributing to both the decline in health of receiving waters (Ladson et al, 2004) and potentially contributing to flooding.
- Importing vast quantities of food into cities. This food will largely be grown in temperate areas which experience net evaporation and therefore require significant irrigation (Pearce, 2006). Water to irrigate is typically extracted from groundwater or rivers. The energy required to grow, harvest, package, store, transport, distribute, dispose of the waste packaging and waste food and then to cook the food have been estimated to account for the release of approximately one third of total European Union carbon emissions (European Commission Technical Report, 2006).
- Importing vast quantities of "virtual" water into cities. Apart from the relatively small volumes of water required to flush toilets, bathe, do laundry and drink, much larger volumes of water are "virtually" imported into cities as a critical production input in all products (Pearce, 2006) that are consumed within a city. For example Hoekstra et al (2007) reported that for the UK, the per capita water footprint was 1245 m^3 while domestically each UK resident only consumes about 38 m^3 per annum. Food consumption in the UK accounts for 810 m^3 or roughly two thirds of the total water footprint per capita per annum.
- Food security becoming a much greater concern mainly due to climate change induced reductions in rainfall and increases in evaporation in temperate areas combined with diminishing oil reserves. Oil production is likely to be peaking at the current time (Hopkins, 2008). Inflated oil prices are already directly impacting on food prices through higher production costs. Biofuel producers are currently competing for land with food producers exacerbating food prices further (Cassman et al 2007).
- The creation of heat island effect in urban areas

Permaculture is a design philosophy which seeks to maximise yields by minimising energy inputs and waste outputs by deliberately and thoughtfully establishing a system of beneficial relationships (Mollison & Holmgren, 1978). Mollison, who co-founded Permaculture, often stated that the problem was the solution. If, according to Mollison, the problem is the solution, then below we redefine the stormwater problem accordingly:

> *The problem is not that urban areas produce excessive quantities of stormwater. On the contrary stormwater is a resource. The problem redefined is that urban areas have a deficit of beneficial uses for the runoff they shed.*

This proposition was tested through a theoretical case study in a densely developed catchment in Melbourne, Australia. This proposition is not entirely without precedent, it is partly based on the exemplar of urban farms in Cuba.

The collapse of the Soviet Union in 1989 resulted in the loss of food subsidies and oil supplies to Cuba almost overnight (Barclay, 2003). In response the Cuban government permitted and encouraged the use of vacant city land for food production and significantly increased production over the next few years.

In this paper we propose to further the Cuban model of urban food production by proposing that water to irrigate urban food crops can be harvested from adjacent impervious areas.

Plate 1 Urban farming in Cuba

In Australia food producing areas tend to be located in relatively dry regions, large distances from the wetter coastal fringe which is where most of the population resides and where most of the associated impervious areas are created. Here we do not view impervious areas as a threat to river health though it has been reported widely, for example by Ladson et al (2004), that unmitigated discharges to rivers do cause a decline in river health, instead we consider there is a shortage of beneficial uses of stormwater.

The benefits of urban stormwater farming would include:

- helping to mimic predevelopment hydrological regimes and restore a natural flow regime to heavily disturbed systems
- abstracting less water from areas where food is currently produced. If this were the Murray Basin in Australia for example it would be of significant benefit given the current levels of water stress
- improved health of urban waterways by reducing pollutant loads
- reducing heat island effects by increasing well watered vegetated areas within the urban fabric whose potential to evaporate on very hot days helps to reduce local temperatures
- reduced peak flows and volumes of runoff in urban waterways during irrigation periods though it is noted that during winter when irrigation demand is lower this benefit would be reduced
- reduced need to consume artificial fertiliser because of the relatively high nutrient content of stormwater
- significantly reduced food miles and associated carbon footprint, packaging and waste for city consumers
- significantly reduced water footprint of city dwellers
- creation of jobs and helping to build local and resilient economies

2 METHOD

A case study to investigate the feasibility and estimate yields and costs of an urban stormwater farm was undertaken. The data for this case study was supplied by STORM_CONSULTING (Storm Consulting, 2009).

Stamford Park is located in the South East of Melbourne. The parkland is currently owned by Knox City Council who will develop the site into a residential development and local community land.

A Masterplan had been prepared for the site which envisioned the 52 Ha site would comprise:

- 7 Ha of residential development
- A plaza and town square

- 45 Hectares of parkland located in the floodplain, essential for the maintenance of floodplain storage
- Up to 30 hectares of riparian rehabilitation
- Heritage homestead conservation

It was proposed to amend the Masterplan so that a bioregional stormwater harvesting and reuse scheme could be put into place with the harvested water used to irrigate 20 hectares of urban farm and community food allotments also known as community gardens. This land use is compatible with the floodplain management objectives of the 45 hectare parcel of land. It was argued that if the stormwater harvesting scheme was used to irrigate the proposed parkland, this would in effect be satisfying a new demand and no genuine water saving would be realised. Food however would be consumed in the catchment regardless of the development and therefore there was an existing virtual water demand associated with that food consumption. Thus if the harvested stormwater was used to grow food locally it would reduce the existing virtual water demand in the catchment.

A core component of the scheme tested in this case study is then the harvesting of stormwater for irrigation of 20 hectares of combined orchard and permaculture gardens and 2 hectares of communal allotments. The stormwater would be harvested from a 300 hectare densely developed urban residential catchment feeding a drainage line which passes through the site. The water would first be treated in a constructed wetland and then stored off-line in the “City Farm dam”, refer to Figure 1.

The Masterplan for the site also included the provision for extensive harvesting of both stormwater and rainwater from the proposed residential development. As part of the case study, harvesting of rainwater from the roofs of all dwellings and then storing in a single communal tank was also investigated. The rainwater was to be reticulated to meet all potable (including drinking) and non potable water needs on the estate following treatment and disinfection.

Harvesting of stormwater from the proposed residential development was also investigated with the stormwater to be harvested to:

1. Passively irrigate street tree pits and rain gardens on approximately half of the estate
2. Irrigate relatively small private open space areas (gardens) within each residential dwelling.

Figure 1 shows the proposed integrated water cycle management system for this site.

2.1 Water balance modelling

A detailed water balance was undertaken to guide the proposed concept design development and to assess the volumes of water that could be saved by the proposal. A sensitivity analysis was also undertaken to ensure that any assumptions made would not impact materially on the real water savings that would accrue in the future.

The water balance model adopts a modified Pulls method. Daily fluctuations of stored water were modelled taking into account rainfall-runoff after initial losses, household internal and external demand for water and evaporative losses from any open storage.

The model was used to then calculate the yields and reliability of the proposed harvesting systems. The demand for outdoor water for irrigation was estimated using the method adopted by the NSW Department of Planning through their Building and Sustainability Index Tool (BASIX) assessment tool (NSW DIPNR, 2004). This method estimates the demand for irrigation (conceptualised as a water deficit) based on the difference between evaporation and rainfall.

Each of the storages created were optimised. The roofwater storage was 700 m3, the stormwater storage was 1 ML and the City Farm storage was 36.4 ML.

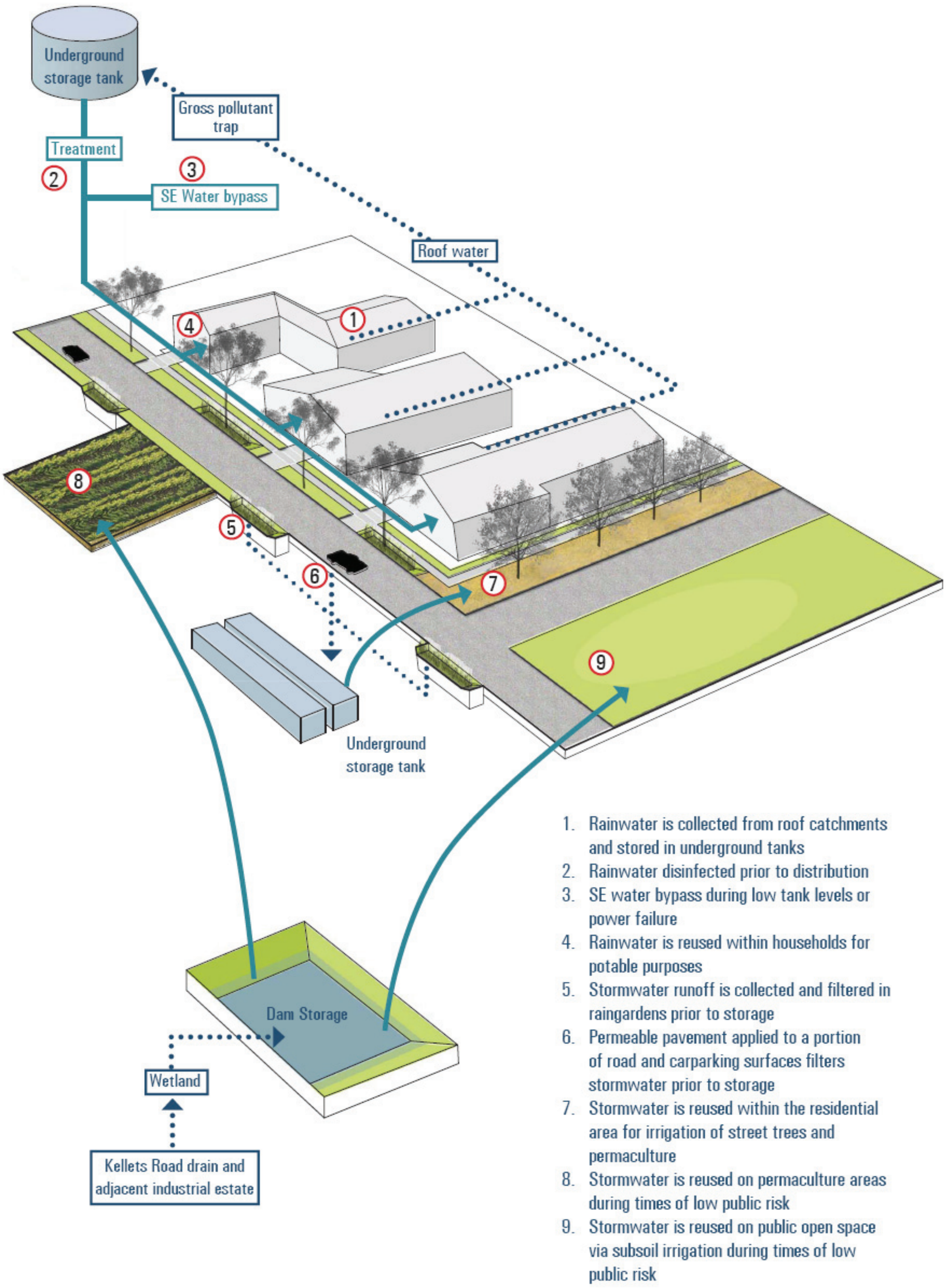

Figure 1 Proposed Integrated Water Cycle Management Schematic

2.1.1 Rainfall and Evaporation

Historical daily rainfall was obtained from the Australian Bureau of Meteorology weather station at Scoresby Research Institute (86104) located 2.3 km from the case study site.

Daily rainfall data from 1948 to 1988 was used to simulate the water balance. The annual average depth of rainfall was found to be 867mm/annum. The data was of particularly high quality with few missing periods. The annual rainfall variation is from about 50mm/month in summer to 95mm/month in early spring-late winter.

Rainfall percentiles were calculated for the 41 years of daily rainfall so that wet, dry and average year performance could be assessed. The year 10 percentile dry year was determined and used to check certainty of supply under extremely dry conditions. Evaporation data (mm/day) from Scoresby Research Institute was used. The evaporation data was used to assess both the depth of evaporation from the proposed storages as well as to assess the demand for irrigation.

2.1.2 Modelled Water Demands

Household Demand

Household water demand was estimated to be 155 kL/day per person. This accords closely with current daily consumption targets and actual water consumption patterns on new developments using water efficient fixtures and fittings (OurWater, 2009).

Private garden irrigation may be undertaken however one should note that there is limited garden areas expected on each lot due to the focus on communal areas. Grey water re-use for garden irrigation will also be encouraged. Although the 155 kL/day per person seems reasonable, a sensitivity test was undertaken which showed that increasing the demand to include significant garden irrigation resulted in only a minor decline in the certainty of supply.

Given all water consumed within a dwelling was to be sourced initially from roofwater there was no need to further disaggregate demand. We assumed an average occupancy of 2 people per dwelling and that 120 dwellings would be developed as part of this estate.

Outdoor Water Demand within the Residential Portion of the Estate

There was an assumed need to irrigate approximately 1 hectare of public open space within the residential portion of the estate and that access to the public open space could not be controlled. This has given rise to the need to treat this water using permeable pavers and a subsoil filter media to ensure it is fit for purpose. Public health risks will be further reduced by irrigating using drip and subsurface irrigation methods.

Outdoor Water demand on the estate was estimated using the NSW BASIX Assessment tool methodology (NSW DIPNR, 2004).

Outdoor Water Demand for the City Farm

We have based the demand estimates for water on the assumption that 20 hectares of orchard and market gardens will be developed using organic methods. Again the NSW BASIX Assessment Tool methodology (NSW DIPNR, 2004) was adopted as described above.

2.1.3 Contributing Catchment Areas and losses

We assumed roof areas amounted to 2.4 hectares and that only roof areas would be piped using a common drainage system to the roofwater storage. No stormwater will be connected to this system.

We assumed that approximately 4,000 m^2 of road would be covered with or drain onto permeable pavers and then into the stormwater storage. We assumed that the external catchment to provide irrigation water for the City Farm was 300 Ha and 40% impervious. We accounted for initial losses from all catchment areas. We also accounted for water lost due to evaporation in a proposed constructed wetland to be located upstream of the City Farm storage and in lakes upstream of the City Farm storage in the 300 hectare external catchment.

3 RESULTS

3.1 Yield Analysis Results

Results from the water balance (Storm Consulting, 2009) are documented below in Table 1.

	Roofwater Harvesting	Local Stormwater Harvesting	Bioregional Scale stormwater harvesting & reuse
Average annual demand (ML)	13.6	4.1	83
Average Annual Supply (ML)	11.4	3.4	67
Average annual top up (ML)	2.18	0.8	16
spill volume (ML)	7.5	6.6	284
Certainty of supply (%)	84	81	81
Certainty of supply during 10% dry year (%)	80	72	68

Table 1 Predicted yields and Certainty of Supply

Tables 1 shows that roofwater can be used to supply 84% of the demand. A single communal tank and disinfection system has the advantage of being able to be maintained cost effectively by a body corporate (Brown et al 2008). Such an approach which excludes stormwater means that the roofwater once disinfected by UV will be fit for drinking. This then permits a single set of water supply pipes to be present within dwellings which has considerable cost savings.

Table 1 shows that stormwater from 50% of roads on the estate if harvested and collected could supply 80% of the outdoor water demand on the common areas forming part of residential estate. Passive irrigation carried out by street pits and rain gardens would occur on the remaining 50% of the estate roads. This permits traditional pipes carrying stormwater to be constructed on less than half of the state. Permeable paving was also used to “soak up” rain and with a subsoil piped network directing the filtered water to the stormwater tank for subsequent reuse.

Table 1 shows that bioregional scale stormwater harvesting system could meet 80% of the demand for water to irrigate crops on the 20 hectare organic orchard and permaculture gardens. This equates to supplying 67 ML per annum on average with a relatively reliable supply during even the 10% dry year. During the 10% dry year the stormwater would not be supplemented with potable water and a result increased stress would be experienced by the orchard and crops. A crop stress analysis has not been carried out however it was found that even during dry years the certainty of supply would be 68% for this system.

3.2 Water Quality and Public Health considerations

At each stage in this case study public health risk and conformance to drinking water and relevant guidelines was carefully considered.

The roofwater harvesting system is arguably the most risky sub-system. It was proposed to use the harvested roofwater to meet all potable and non-potable demand on the site. The water was to be filtered to remove suspended solids and then disinfected by a UV system. There are issues and considerations such as water colour, odour and taste which would not be addressed by simple mechanical filtering and disinfection however risks to public health are considered to be acceptable.

Passive irrigation of street trees with stormwater poses no obvious risk to public health and has been shown to significantly improve water quality (Breen et al, 2004).

Surface irrigation using harvested stormwater in uncontrolled areas was only proposed following UV disinfection to ensure risks from spray drift and aerosols were minimised.

The community garden itself would be a controlled area with access permitted only during daylight and irrigation taking place during the night. Treatment of the urban stormwater was to take place in a constructed wetland prior to storage. The wetland was designed to achieve best management practice which effectively removes suspended solids, nutrients and some pathogens from the flow. Because the treated stormwater was only to be used to irrigate areas with controlled access it is not necessary to first disinfect the water. In addition passive risk management measures such as the use of subsoil irrigation would be employed to further minimise the risk wherever appropriate.

There are some uncertain elements of this proposal in terms of the risk to public health from consuming food products irrigated with treated urban runoff. Urban runoff has been shown to contain toxic levels of dissolved Copper and Zinc (Liebman et al, 2009) which may bioaccumulate if water containing dissolved metals is used to irrigate food crops. However it is suggested that levels of dissolved metals would be enable compliance with Australian Drinking Water Guidelines (the dissolved metals in question become to toxic to aquatic organisms at much lower concentrations than for humans) and on that basis the water would be fit to irrigate food crops.

4 DISCUSSION AND CONCLUSIONS

The case study has shown that it is possible to construct bioregional stormwater harvesting schemes and to use that water to grow fresh fruit and vegetables close to consumers. Based on the simple payback method and using 2013 water prices it would take 13.9 years to recover the cost of putting in place the large farm dam harvesting and irrigation infrastructure. This does not take into account the value of food produced and its contribution to reducing the payback period.

Based on yield estimates by Crooks (2009) and food prices documented by Stewart (2006) we have estimated the annual retail value of food produced from the city farm to be in the order of AUD$680,000. The 2006 food prices reported by Stewart do not reflect more recently inflated oil prices which have driven up food prices markedly in recent times. That is the value of food production is likely to be underestimated.

We acknowledge water has been valued at Melbourne urban consumer prices. In reality water in rural areas is extracted at a fraction of the urban retail price with raw water possibly costing less than 50 cents a kilolitre. However in a practical sense, during a period such as this when there is a distinct lack of water in Australian food producing areas and where crop yields have in some cases fallen by 98% (Bradsher, 2008), the cost of rural water is irrelevant.

Over a 25 year period the system is likely to save over 2 billion litres of water. This claim is based on the concept of virtual water whereby we know that water would otherwise be abstracted from a river to grow food to sustain the urban population in Melbourne. The capital component of the cost per kL of reused stormwater over a 25 year period was found to be $3 and operational costs are conservatively estimated to be in the order 50 cents per kL resulting in a total cost of $3.50/kL. The costs of water in 2013 based on current gazetted water rates will be $4/kL. The bioregional system therefore is of sufficient scale to permit harvesting and supply of water at prices marginally lower than future urban retail water prices.

The reduction in food miles and associated carbon emissions is complicated to calculate and will depend on a number of unknown factors such as where food is produced and types of transport. In 2007-2008 it was estimated that vegetable farms in Australia produced on average 28 tonnes of vegetables per hectare per year (Crooks 2009). We have assumed that the city farm would be operated on a commercial basis for illustrative purposes. Though we have no accounted for it, it is likely that the city farm would yield more than a rural commercial farm because of the high certainty of supply (81% certain) and water efficient irrigation infrastructure (drip and subsoil irrigation allowed for in the cost estimate) combined with the higher yields associated with permaculture practices. The city farm therefore is assumed as having the potential to produce approximately 560 tonnes of fruit and vegetables per annum.

Adopting values reported in Gaballa et al (2007), and assuming the city farm will produce equal quantities of apples, tomatoes, potatoes, pumpkin, lettuce, carrot and tomatoes; the average distance travelled for these food items is 485km. This would equate to a reduction in carbon emissions associated with only the transport of the food by 60 tonnes per year, assuming that the food is produced within walking distance of the intended point of consumption as is the case in our example (Gaballa et al, 2007). Avoiding the embodied energy in packaging, cold storage on supermarket fridges and waste disposal of packaging would also contribute to further reducing greenhouse emissions.

Many aspects of this project are inherently difficult to value and beyond the scope of this paper. It is however important to recognise the non-monetary values provided by a project of this nature and not evaluate the benefits simply on the basis of the value of water saved. It is interesting to note that without having the benefit of the concept of virtual water it would be difficult to demonstrate that the food producing aspect of this project would save any water at all.

From this study it is also clear that there is a significant link between land use planning and pollution.

The current land use planning paradigm adopted by the developed nations of the world is to construct large urban agglomerations serviced by commercial super markets which import large quantities of food from rural areas. Such land use practice is considered to be unsustainable because of the energy required to sustain it and the pollution (especially water pollution) that it produces. This project shows that mixing the land uses within a regional area enables highly beneficial and more sustainable relationships to be put in place, in other words they allow a permaculture approach to be applied. Such approaches have been termed bioregional approaches (Desai et al, 2002). In this case allowing a farm to be developed next to a densely developed residential area will have a significant beneficial impact on the health of the receiving waters and the health of waterways elsewhere through reduced abstraction. It will also result in the reduced emissions of more than 60 tonnes of carbon. The local community will benefit from organically grown fresh fruit and vegetables irrigated with their stormwater.

At this time there have been a large number of successful stormwater harvesting projects that have been developed in Australia and elsewhere. Relative to other aspects of urban hydrology, where rainfall records are of good quality and a detailed water balance is undertaken it is considered that there is little uncertainty associated with stormwater harvesting projects. It is beyond the scope of this paper to comment further on the uncertainty except to conclude that a large number of successful projects implies that the risk and uncertainty can be managed effectively by skilled practitioners.

The authors of this paper have collectively designed and implemented more than 20 successful harvesting and reuse projects but they have all harvested water to meet strictly urban uses such as irrigation of golf courses, parks and rainwater for various non-potable uses. However this paper has shown that stormwater can be harvested from urban areas and used to irrigate food crops grown in the same urban areas using the Cuban food production model. Harvesting urban stormwater combined with “city farming” can then be shown as one technique which will reduce urban runoff (both volumes and pollutants), reduce carbon emissions and reduce virtual water consumption.

We suggest that stormwater harvesting is no longer embryonic and it has proven to be viable with manageable public health risks. It is therefore recommended that future research needs to focus less on the technological aspects and more on creating and evaluating the multiple benefits that can accrue so that their true social and economic contributions can be identified and included in any cost benefit analysis.

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