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A Review on Stormwater Harvesting and Reuse

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***Abstract*—**Australia is a country of some 7,700 million square kilometers with a population of about 22.6 million. At present water security is a major challenge for Australia. In some areas the use of water resources is approaching and in some parts it is exceeding the limits of sustainability. A focal point of proposed national water conservation programs is the recycling of both urban stormwater and treated wastewater. But till now it is not widely practiced in Australia, and particularly stormwater is neglected. In Australia, only 4% of stormwater and rainwater is recycled, whereas less than 1% of reclaimed wastewater is reused within urban areas. Therefore, accurately monitoring, assessing and predicting the availability, quality and use of this precious resource are required for better management. As stormwater is usually of better quality than untreated sewage or industrial discharge, it has better public acceptance for recycling and reuse, particularly for non-potable use such as irrigation, watering lawns, gardens, etc. Existing stormwater recycling practice is far behind of research and no robust technologies developed for this purpose. Therefore, there is a clear need for using modern technologies for assessing feasibility of stormwater harvesting and reuse. Numerical modeling has, in recent times, become a popular tool for doing this job. It includes complex hydrological and hydraulic processes of the study area. The hydrologic model computes stormwater quantity to design the system components, and the hydraulic model helps to route the flow through stormwater infrastructures. Nowadays water quality module is incorporated with these models. Integration of Geographic Information System (GIS) with these models provides extra advantage of managing spatial information. However for the overall management of a stormwater harvesting project, Decision Support System (DSS) plays an important role incorporating database with model and GIS for the proper management of temporal information. Additionally DSS includes evaluation tools and Graphical user interface. This research aims to critically review and discuss all the aspects of stormwater harvesting and reuse such as available guidelines of stormwater harvesting and reuse, public acceptance of water reuse, the scopes and recommendation for future studies. In addition to these, this paper identifies, understand and address the importance of modern technologies capable of proper management of stormwater harvesting and reuse.

***Keywords*—**Stormwater Management, Stormwater Harvesting and Reuse, Numerical Modeling, Geographic Information System (GIS), Decision Support System (DSS), Database.

I. Introduction

WATER is essential to our quality of life, economic growth, and to the environment [1], [2]. There is sufficient water on this planet, but the availability of this water varies in geographic terms, in time and in quality. Quality water is essential for ecosystems development and production processes [3]. But at present around the world, freshwater scarcity is becoming an increasingly significant problem for many countries. When the annual supply of renewable freshwater of a country is less than 1000 m^3 per capita, the country is considered as water-scarce [4], [5]. In Asia and elsewhere there are many towns where the demand for potable water doubles every 10-15 years [6]. In case of Australia, the usage of water resources is very close to exceeding the limits of sustainability in some parts like South Australia, South-East Queensland, etc. Actually the demand of water increases due to continuous population growth, intensive agricultural development, urbanization and rapid growth of the industry. Besides, there are uneven distribution of water resources and the impact of climate change, like periodic droughts which worsen the situation. This expanding water demand should be met in the longer-term.

Water is a precious finite resource. Day by day, the use of water may become a luxury for society. In this situation, reuse and recycle of water can be a potential solution. The alternative water supplies considered for reuse are rainwater, stormwater, greywater, treated sewage, industrial water and managed aquifer recharge (MAR). For consideration of alternative water supplies, it is important to choose the most appropriate water source taking into account the risk, resource and energy requirements [7]. In nature absolute pure water is rare. Water quality is determined by the micro biological, physical, chemical and radiological characteristics of water [2]. The quality of stormwater is comparatively better than untreated sewage or industrial discharge, and it therefore more readily achieves public acceptance for its reuse and recycling [8]. Before 1980s, stormwater was not considered as a valuable resource. The prime aim of stormwater management was to dispose stormwater as quickly as possible to receiving water bodies [9]. As a result the receiving water bodies were adversely affected by pollution. Stormwater pollution includes litter (i.e. cigarette butts, cans, food wrappers, plastic bags or paper), natural pollutants (i.e. leaves, garden clippings or animal faeces), chemical pollutants (i.e. fertilizers, oil or detergents) and sediment pollutants (i.e. soil erosion and runoff from building sites and unsealed roads) etc. The impurities occur in three progressive finer states- suspended, colloidal and dissolved. These pollutants are created by urbanization, development and populating of an area and carried to inland water bodies such as streams, rivers, and lakes by stormwater and deteriorate their quality and endanger their ecosystems.

Stormwater is a precious resource if we can manage it properly. Otherwise it may lead to flooding of urban areas and

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deterioration of water quality in rivers and receiving waters [9]. The primary purpose of stormwater management is to prevent and alleviate the impacts of stormwater runoff by applying proper stormwater control or treatment measures [10]. Stormwater management means the management of both the quantity and quality of stormwater [11]. Sustainable management of stormwater can be defined as the management of stormwater which meets the needs of the present without hampering the ability of future generation to meet their own needs [12]. Sustainable stormwater management causes some benefits such as control flooding and erosion; prevent pollutants from directly discharged into the environment; remove contaminants before polluting the surface waters or groundwater resources; attain and protect natural waterways in their own places; address inclusive stormwater needs by revising current stormwater regulations; create solutions before problems become too big by planning carefully. Effective stormwater management ensures a balance between economic costs, environmental benefits and the society to get a more sustainable future i.e. survival in the long run. The practices that provide long term success of stormwater management scheme are referred to either as Best Planning Practices (BPPs) or Best Management Practices (BMPs). Two types of BMPs are available; non-structural BMPs and structural BMPs. One threat to sustainable management of water is climate change. In Australia rainfall is more variable than the rest of the world as here rainfall is driven by the southern oscillation rather than by seasonal changes. This highly variable precipitation levels have an effect on effective water management in Australia.

However, realizing the increased stress on mains water supply systems, the harvesting of stormwater to supply non-potable water demands is becoming an important and feasible option. In Queensland stormwater harvesting and reuse have already been recognized as a potential alternative for potable water demand reduction [13], [14]. Use of modern technologies is viewed important for the efficient assessment of feasibility of stormwater harvesting and reuse projects. Nowadays stormwater system cannot be conceived without the use of computer modeling and spatial techniques. Additionally integration of a consistent database with stormwater model and GIS (Geographic Information System) is the central idea behind hydroinformatics. As a result evolution of decision support system (DSS) occurred that additionally integrate evaluation tools and Graphical User Interface.

In the next section, storm water harvesting and reuse issues are described. In Section III the integrated technologies used in stormwater research are reviewed which includes stormwater model, geographic information system, regional database and decision support system. Useful management tools that have been incorporated in storm water models are described here. National and state guidelines of Australia for Stormwater harvesting and reuse are listed in Section IV. Social impacts and public acceptance of water reuse are described in Section V. Shortcomings of current practices, propose directions for future research, and conclusions are listed in Sections VI and VII respectively.

II. Stormwater Harvesting and Reuse

Stormwater harvesting and reuse is one of the key stormwater management measures. Stormwater harvesting refers to the collection and storage of stormwater during significant stream flow and reuse it at later times when less water is available. In a stormwater harvesting and reuse scheme, various combinations of elements can be used depending on the nature of the site and the end users. But the most common four components are collection, storage, treatment and distribution. Generic stormwater harvesting flow diagram is shown in Fig. 1.

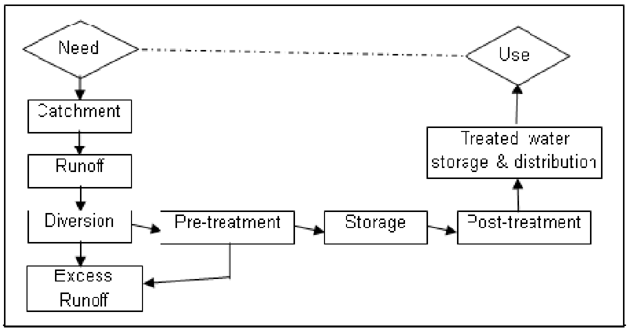

Fig. 1 Generic Stormwater Harvesting Flow Diagram (Source: [15])

Stormwater harvesting is very close to rainwater harvesting. Here runoff is collected from drains or creeks or waterways, whereas rain is collected from roof in the later case. Both have broadly similar benefits in reducing pollution loads, downstream stormwater flows and demand for mains water. However, there are some differences in costs, stakeholders, maintenance, and health risks between these two approaches. Combined rainwater and stormwater collection and reuse schemes can be implemented successfully for medium-density developments, in which reticulation costs are relatively low.

Treatment of stormwater is a vital part of stormwater harvesting and reuse. The aim of water treatment is the elimination of unwanted contaminants such as pathogens and pollutants [16]. But the degree of required treatment varies depending on the specific reuse application of water and associated water quality requirements [3]. For example, most waters need to purify if they are used for potable purposes, but water treatment is rarely required for agricultural purposes. There are three levels of stormwater treatment. At the primary level, physical screening (or trapping) and rapid sedimentation are the dominant processes. This removes the inflow litter and coarse sediment. At the secondary level, sedimentation and filtration dominates. It removes suspended solids, some nutrients and metals. At the tertiary level, the dominant processes are enhanced sedimentation, filtration, biological uptake and adsorption. This improves retention of nutrients and heavy metals. However, till now full water treatment is considered as luxury in some parts of the world. Full water treatment consists of pre-treatment (with or without chemicals), mixing, coagulation, flocculation, settlement, filtration and sterilization [6]. Among these treatments, settlement can remove maximum percentage (up to 90%) of the suspended solids. There are many stormwater treatment measures available; amongst them some important stormwater treatment measures are litter baskets and pits, litter racks, sediment traps, gross pollutant traps, litter booms, catch basins, oil/grit separators, filter strips, grass swales, extended detention basins, sand filters, infiltration trenches, infiltration basins, porous pavements, constructed wetlands etc [2]. In most of the cases, different stormwater treatment measures are used in combination to reduce pollutants through different processes that provide the best overall runoff treatment. Most water treatment technologies that are widely used in developed and developing countries are simple, but proper attention should be given to the cost and appropriateness of the technology during the selected time.

Stormwater harvesting schemes can be developed for new developments or existing urban areas. Most of the stormwater reuse projects are made for nonpotable applications such as residential uses, including: toilet flushing, garden watering, car washing; irrigating public areas, golf courses, agriculture and industrial uses [8], [17]. Other categories for reuse applications are groundwater recharge, ornamental ponds and water features, fire fighting and environmental flow provision. When groundwater is recharged with reclaimed water, it replenishes some part of potable groundwater. However the potable use of stormwater is not commonly practiced in Australia [1]. Water reuse application depends on several important factors such as water quality, types of technology, matching supply with demand, infrastructure, affordability (economic consideration) and environmental mitigation. It is also essential to know the timing and quantity of water required and available. Two stormwater harvesting schemes never be the same. Some stormwater reuse techniques are aquifer storage and recovery (ASR) or Aquifer storage, transfer and recovery (ASTR); urban lakes; constructed wetlands, ponds, rainwater tanks, sediment basins, bioretention swales, bioretention basins, sand filters, swale/buffer systems, Infiltration measures, water sensitive urban design (WSUD), water harvesting, industrial reuse and unplanned reuse [18]. For high volume storage of runoff in a small footprint area, underground stormwater detention may be selected. Some benefits of stormwater harvesting are: to reduce high quality potable water consumption by using non potable water for household garden watering, toilet flushing, irrigation, etc.; minimize polluted stormwater runoff and treat it to a standard which is suitable for reuse or discharge to waterways; preserve the natural hydrologic regime of catchments; preserve natural bush land and streams; ensure an ecologically sustainable stormwater system. Some potential limitations which may hamper stormwater harvesting process are: irregular rainfall pattern; environmental impact of storages; potential health risks; relatively higher unit costs of treated stormwater than the retail cost of mains water; comparatively higher unit cost than rainwater tanks, etc. A successful stormwater harvesting system fulfills potential benefits, tackles public health and environmental risks and achieves the support of key stakeholders. Moreover it has to be cost-effective and sustainable.

The notable benefits of water reuse are: it i) provides a sustainable alternative water supply, ii) uses less energy than importing water, iii) provides controlled supply, iv) avoids construction of new supply development, v) reduces the quantity of treated wastewater discharged to sensitive surface waters, etc. [19]. On the other hand, some principal issues, barriers and impediments of water reuse are i) lack of available funding, ii) need of public education, iii) better documentation on economic treaties on water reuse, iv) need of support from politicians and governments, v) need to conduct etc. [19].

III. Technologies in Stormwater Study

Stormwater management is a complex issue. For better management of that, there is a strong need to apply proper technologies to facilitate effective design of such systems.

A. Stormwater Models

Stormwater models are used to simulate the movement of stormwater across a watershed in response to precipitation and watershed conditions [20]. Computer models have been used to simulate the storm water quantity and quality since the early 1970s [21]. Primarily these models were developed by US government agencies, like the US Environment Protection Agency. Till today literally there are hundreds of stormwater models developed by academic institutions, regulatory authorities, government departments and engineering consultants that are capable of simulating water quantity and quality in an urban catchment [21]. These models include very simple conceptual models to complex hydraulic models. But those are not suitable for any situation. Before the selection of a particular modeling software, some considerations should be implemented according to the objective of the study such as nature of study; budget of the study, catchment size and type; data availability; accuracy or precession level required for the study; integration of GIS with hydrologic and hydraulic model etc. A thorough analysis is required knowing the advantages and limitations of the nature of the study to achieve the goal. There are few studies available on different stormwater model. Zoppou [21] examined twelve stormwater models for simulating quantity and quality of stormwater in an urban environment. Stormwater models can be classified in many different ways. Models can be classified as either deterministic model or stochastic model. Deterministic model always gives same result for the same input values. But stochastic model always produces different model response, as here one or more variables are selected at random from a distribution. Again deterministic and stochastic model can be either conceptual or empirical depending on the presence of physical law in the model. Model can further be classified as event model or continuous model. Event model is a short termed model that simulates a single or few storm events. Continuous model simulates overall water balance of a catchment for a long period. Moreover a stormwater model can work as a planning model or operational model or design model. However a computer model is more popular to be classified as hydrologic model or hydraulic model.

B. Hydrologic and Hydraulic Model

The computer model is more popular to be classified as hydrologic model or hydraulic model. Hydrologic model simulates the rainfall-runoff process and generates surface and sub-surface runoff such as peak flow, runoff volume and runoff hydrographs from precipitation excess. It also generates the wash off and buildup of pollutants from impervious surfaces. The generated flow and pollutants from hydrologic model then is routed through the stormwater infrastructure such as open channel, pipe networks and storages by Hydraulic modeling. Hydraulic model uses the known flow amount as input that is the output of Hydrologic model. Hydraulic model generates useful information such as flow height, velocity and location. Hydrologic models mostly use only continuity equation. Whereas hydraulic models solve both the quantity equation as in (1) and the momentum equation as in (2) which are combined known as the full dynamic equations or the St. Venant equations [22].

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \qquad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (\frac{Q^2}{A})}{\partial x} + gA\frac{\partial y}{\partial x} = gA(S_o - S_f) \qquad (2)$$

where Q= discharge; A= Cross-sectional flow area; q= lateral inflow or outflow; g= acceleration due to gravity; y= flow depth; S_o= channel slope; S_f= Friction slope; t= time; x= displacement in the flow direction.

In 2011 a study was done by Basnayaka and Sarukkalige where two approaches, hydrological approach and hydraulic approach were used for surface routing. It was found that both the approaches are capable to represent urban catchment more accurately though the result showed that the hydrological approach was more accurate [23].

In general storm water models simulates both quantity and quality of storm water flowing through stormwater system, like over the land, open channels, pipe networks and storages. Therefore, two basic components of storm water models are: stormwater quantity modeling and stormwater quality modeling.

C. Stormwater Quantity Modeling

Computation of stormwater quantity is required to design the stormwater system components based on catchment size, geographic location, weather conditions and purpose of water use. It considers all the major hydrological processes; like evapotranspiration, overland flow, interflow and groundwater flow. To simulate the stormwater runoff most urban catchment models use hydrologic and hydraulic computations mainly for the loss modeling, overland flow modeling, pipe or channel flow modeling and modeling of flow through storages. Different models use different methods to compute these hydrologic and hydraulic responses. Among these, loss modeling receives less priority [24]. Loss modeling includes depression storage of impervious and pervious area; infiltration loss of pervious area and evaporation loss. Overland flow component deals with both impervious and pervious areas using different approaches, such as i) Time-area routing approach ii) Linear reservoir representation, iii) Nonlinear reservoir representation, iv) Muskingum routing approach, v) Nonlinear with time lag, vi) Nash cascade, vii) Time of entry and viii) Unit hydrograph approach. To model pipe and channel flow different methods have been used which include i) unsteady flow models, ii) steady flow models, iii) time-lag method, iv) linear and nonlinear reservoir routing and v) Muskingum routing. To model flow through storages, modified Puls and Muskingum routing methods are mostly used [9]. Most stormwater models compute stormwater runoff using hydrologic methods and then the stormwater runoff or volume is routed through the pipe system or other system components using hydraulic methods. Though there are some models that lumped hydrology and hydraulics together in computing flow hydrographs or peak discharges. Choice of models depends on the type of the catchment, the availability of catchment data, the level of complexity and sophistication required in the simulation of the catchment runoff response and time available for the analysis. Inputs of rainfall runoff model are rainfall, evapotranspiration, digital elevation model (DEM) and land use maps; and output is surface runoff hydrograph. Two important calibration parameters of runoff modeling is the imperviousness and runoff coefficient.

Estimation of model parameters is one of the important requirements of using mathematical models for stormwater catchment modeling. The ideal method of estimating these parameters is to calibrate the models using observed rainfall and runoff data in gauged catchments. But in Australia most urban catchments are ungauged. The percentage of inaccuracies in runoff peak and volume for ungauged catchments is comparatively higher than that of gauged catchments. As a result, designers are reluctant to use the computer models. Therefore, it is necessary to develop regional equations to estimate model parameters of widely used computer models for the ungauged catchments. Regional equations define the model parameters as functions of measurable catchment properties and storm characteristics. In Australia, very few studies have been conducted where regional equations have been developed for ungauged urban catchment. For example, in 2001, Dayaratne derived two regional equations for impervious area parameters for the directly connected impervious area, supplementary area and directly connected impervious area depression storage using only 16 residential catchments in Melbourne metropolitan areas where size varied from 3 to 30 ha [9]. Therefore, the validity of these regional equations outside of this area ranges and mixed land-use catchments should be tested for further use. Furthermore, guidelines and improved methods are required for the simulation of peak discharge and runoff volume of ungauged catchments. It is also important to check the level of accuracy of computer models which is done by many factors like objective function, root mean square function, etc. The uncertainty of model output caused by model calibration parameters should be investigated. Yu et al.

[25] used four methods, the Monte Carlo simulation (MCS), Latin hypercube simulation (LHS), Rosenblueth's point estimation method (RPEM), and Harr's point estimation method (HPEM), to build uncertainty bounds on an estimated hydrograph. Different literature on model uncertainty are found in Zoppou [21].

D.Stormwater Quality Modeling

Water quality model predicts the water pollution to identify the type of treatment required using mathematical simulation techniques. For assessing stormwater quality, the key parameters that have been widely used are P_H, electrical conductivity (EC), total nitrogen (TN), total phosphate (TP), total suspended solids (TSS), and biochemical oxygen demand (BOD) [26]-[29]. Particularly in case of drinking water; appearance, taste and odor are also useful indicators. The water quality data helps to improve the understanding of specific physico-chemical processes and interactions that govern the transformation of pollutants in stormwater. In turn, this knowledge is essential for the selection of appropriate treatment measures required for a specific purpose.

Modeling water quality in stormwater requires equations that describe the build-up of pollutants in catchments during dry periods and the rate of pollutant wash off during storm events. Typically, separate equations are developed for the simulation of each pollutant-land use combination [24]. For example, in XPSTORM [30], the TSS is modeled using the Event Mean Concentration (EMC) method and BOD is modeled with the rating curve by using (3).

$$C = C_{oeff} * R_{exp} \tag{3}$$

where; C = concentration in runoff (mg/L); C_{oeff} = user defined wash off coefficient; R = runoff flow (m^3/s) and exp = user defined exponent.

At present in Australia as well as in the world a lot of hydrologic and hydraulic modeling packages are available for the assessment of stormwater quantity and quality. In Australia some widely used modeling software for runoff routing are AWBM [31], NAM [32], XP-RAFTS [33], XP-STORM, SIMHYD [34], Sacramento model [35] etc. Some are free modeling software available to the public, like HEC-HMS [36], WaterGEMS, etc. Besides, nowadays many of the hydrological modeling software incorporate water quality modules to know the water quality parameters. For example, XP-SWMM [37], XP-STORM, MIKE-SWMM, MIKE-URBAN [38] etc. incorporates hydrology, hydraulics and water quality modules in an integrated manner. Some popular hydraulic modeling software are MIKE11 [39], XP-STORM etc. Moreover, many of these modeling softwares have several tools to integrate GIS data into the modeling environment. Numerous studies have been done using these modeling softwares. For example Chow, Yousop and Toriman simulated runoff quantity and quality in residential, commercial and industrial catchments using SWMM [40].

E. Geographic Information System (GIS)

The application of Geographic Information System (GIS) technology in the field of stormwater study is widespread nowadays [41]. Shamsi et al. [42] found that more than 70% of the information on local governments is georeferenced. Mostly has already been or will be transferred into a digital format, GIS. For example, Inamder et al. [43] used GIS based screening tool for the selection of suitable stormwater harvesting sites. To model catchment scale hydrology and stormwater runoff, spatial analysis using GIS is needed. For example Fatema et al. [44] delineated the sub-catchment of the study area from a large Fitzroy basin for the development of hydrologic model using GIS capabilities. Using Digital Elevation Model (DEM) data, GIS can extract elevation and generate stream flow direction map by calculating the steepest downhill slope for each cell. DEMs are also capable to extract catchment characteristics providing flow direction and sub catchment boundary map [41]. In local governments and consulting firms GIS and spreadsheet modeling capacities are widely used for runoff modeling [45]. For example, urban water security research alliance used GIS based runoff modeling for strategic stormwater harvesting assessment and found harvestable annual volumes of stormwater for different scenarios [45].

Therefore, nowadays most of the stormwater modeling software has linkage with GIS. Sample et al. [46] reviewed the application of GIS technology in the field of urban stormwater modeling and for this purpose they surveyed around 50 literatures. The relationship between GIS and stormwater models may be distinct or blurred. Either GIS functions as a separate pre- and post-processor of the spatial data or the model may be seamlessly integrated into the GIS. In the first case, when GIS functions as a pre-processor, it simply stores geographic information in a database or it calculates model-input parameters from stored geographic data. These data are frequently exported to a file format consistent with a model-input file. As a post-processor, GIS produces map of water surface elevations, concentrations, etc., or derives spatial statistics based on model output. For example the relation between GIS and SWMM is distinct, with no direct interlink. The GIS is used to extract data from the spatial database and converted the data into a file compatible with a SWMM input file. Shamsi [47] explains the transfer of data from a GIS to SWMM. At present there are many models that utilize GIS information; but the integration remains debatable. However, two factors limiting the use of GIS in stormwater modeling are i) requirement of large, expensive and detailed spatial and temporal databases, and ii) Lack of good integration of many computer tools used in urban stormwater modeling with GIS.

F. Database and Decision Support System (DSS)

In the decision process only model is no longer the central unit. Neither the GIS becomes the central data tool, due to its inability to handle temporal information effectively. To achieve considerable success, equal attention is needed for the model, the GIS and the temporal information [46]. Therefore the integration of GIS and urban stormwater models should be integrated with a database structure to handle time series.

To manage all of this information a system is required where an integrated suite of tools will provide full support to a complex hydrologic decision. These tools are referred to as Decision Support Systems (DSS). Reitsma [48] defines DSS for water resources applications as “Decision support systems are computer-based systems which integrate state information, dynamic or process information, and plan evaluation tools into a single software implementation”. DSS has normally been applied to complex unstructured water resources and environmental problems. DSS includes simulation models (e.g. SWMM, MOUSE, HydroWorks), GIS (e.g. ArcView, IDRISI, ArcInfo), relational databases (e.g. Dbase, Oracle, Access), evaluation tools (e.g. optimization software) and a graphical user interface. From the explosion of the computer software, it is apparent that too much reliance on any one technology can lead to obsolescence. DSS enables the analyst to explore new challenging problems in old the context through linking many of these tools together.

IV. Guidelines or Regulations for Stormwater Harvesting and Reuse

Like other countries, Australia has national guidelines or regulations for recycling water from effluent, greywater, stormwater, managed aquifer recharge and drinking water in various conditions of development or implementation. Guidelines for specific states and territories are also available as they are more appropriate for local ultimate end users.

Australian Rainfall and Runoff (ARR) is one of the most influential and widely used national guidelines published by Engineers Australia (EA) for the estimation of design flood characteristics in Australia. Since its first publication in 1958, ARR has retained the same level of national and international approval till the current edition, published in 1987. It is very significant for overland flow modeling. ARR87 proposed many relationships relating runoff coefficients and time of concentration to factors such as land-use, surface type, slope, and rainfall intensity for the statistical rational method. Besides ARR87 assists in selecting the average recurrence interval (ARI) or return period of design flow. ARR87 gives recommendation to select the critical storm duration and to develop Intensity-Frequency-Duration (IFD) curves. Besides stormwater systems, ARR are essential for policy decisions and many other projects involving; i) infrastructure such as roads, rail, airports, bridges, dams and sewer systems; ii) town planning; iii) mining; iv) developing flood management plans for urban and rural communities; v) flood warnings and flood emergency management; vi) operation of regulated river systems; and vii) estimation of extreme flood levels.

The guidelines for the values of calibration parameters like imperviousness and runoff coefficient of rainfall runoff modeling can be found from Water by Design, Queensland Urban Drainage Manual, Melbourne Water, etc. [15], [49], [50].

“Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse (AGWR)” is the national, non-mandatory guidance on managing potential public health and environmental risks from reusing non-residential roof water and urban stormwater for non-potable end uses only [51]. This publication has been endorsed and released in combined by Natural Resource Management Ministerial Council, the Environment Protection and Heritage Council, and the National Health and Medical Research Council in July 31, 2009. Councils should refer to the AGWR Phase 2 guidelines for the management of environmental and health risks, as they reflect the most up to date research and information. It provides guidance on managing environmental and health risks associated with stormwater harvesting and reuse projects. It is designed to provide an authoritative reference to support beneficial and sustainable recycling of waters generated specifically from stormwater, which represent an underused resource. This document does not address i) the strategic context, impact and feasibility assessment and design of reuse schemes ii) rainwater reuse using domestic rainwater tanks iii) combined effluent and stormwater reuse schemes iv) harvesting stormwater from predominantly non-urban catchments (e.g. rural or forested) v) irrigation schemes using river water vi) public safety, occupational health and safety, operations or construction-phase environmental management. Originally this document was built on the document ‘Managing Urban Stormwater: Harvesting and Reuse’ which was released by the then Department of Environment and Conservation (DEC) in 2006 [18]. Now it is known as the Office of Environment and Heritage. The DEC Guidelines are a useful tool for the planning and implementation of stormwater harvesting and reuse projects. Now it is the state guidelines for NSW.

In Victoria the use and required quality of stormwater is not specifically regulated. However, the right to harvest stormwater and the construction of stormwater schemes may be subject to regulation. For Victoria, EPA (Environment Protection Authority) Victoria has released some guidelines for Stormwater Harvesting and reuse. EPA Victoria published so many guidelines regarding water for the Victoria as well as for Australia, i.e. Australian Guidelines for Stormwater Harvesting and Reuse; Guidelines for Urban stormwater best practice environmental management guidelines; Australian Runoff Quality: A guide to Water Sensitive Urban Design; etc. As there are no specific laws on stormwater using or quality standards, it is the duty of responsible party to make sure that the stormwater schemes will not place any risk on people or the environment. Supporting guidance is available for both single residential properties and multi-residential and commercial sites [7].

Stormwater Management Manual for Western Australia (Department of Water 2004-2007) replaces the Manual for Managing Urban Stormwater Quality in Western Australia (Water and Rivers Commission 1998) to reflect the new approach to stormwater management. Government of Western Australia released the manual for local government, industry, developers, State agencies, service providers and community groups. It provides planning and environmental policies as well as on-ground best practice advice. In keeping with the national guides, it provides specific Western Australian guidance as stormwater management in Western Australia is unique, as both stormwater and groundwater may need to be managed concurrently [52]. For the presence of superficial aquifer, drainage channels can commonly include both stormwater from surface runoff and groundwater here.

Department of Energy and Water Supply of Government of Queensland realized several guidelines regarding water recycling management, water quality etc. for Queensland [53]. Besides, to support sustainable urban water management, Water by Design offers a range of best practice guidelines. The guidance includes water sensitive urban design, total water cycle management, erosion and sediment control and managing waterbodies [15]. The most relevant guidelines of stormwater harvesting for the local community is the Stormwater Harvesting Guidelines. These assist engineers and other professionals to plan, design and implement stormwater harvesting schemes in local catchments and reusing it within the local community. The guidelines provide typical processes and issues that should be addressed when developing a stormwater harvesting scheme.

Moreover it is the reader's duty to read the guidelines entirety as the various parts of stormwater harvesting schemes are interconnected. The user of guidelines should not use specific aspects of the guidelines in isolation.

V. Social Impact and Public Acceptance of Water Reuse

Public acceptance is one of the key factors of successful implementation of reuse projects. User acceptance largely depends on the necessity for alternative water sources. When water is limited, reuse applications are generally better accepted by the community. In Australia most of the implemented reuse projects have been carried out on a small scale and are usually intended for non-potable purposes, such as landscape irrigation, agricultural or horticultural irrigation, industrial water recycling, residential garden irrigation, toilet flushing, recreational reuse, on-site greywater reuse, surface water augmentation, groundwater recharge etc. Water reuse seems to be widely accepted by the Australian Community though very few social studies have been conducted so far [54]. In 2003 a focus group generated by the Water Corporation of Western Australia showed that the idea of using recycled water among the people is very positive. Melbourne Water (1998) and Sydney Water (1999) found the same findings through the studies on community perceptions of water reuse [54]. Higgins et al. [55] did a survey among the users and providers of recycled water in Queensland, Australia, to determine concerns about recycled water quality and directions for applied research. Around 79% of respondents had concerns about water quality. Among them only 33% recommended for the necessity of further research on recycled water quality. 52% of providers and 19% of current users recommend to expand their recycle water usage and 30% of non-users are interested to commence water reuse within the next 5 years. However, the widespread acceptance for water reuse in the Australian community does not mean that any reuse projects will be readily accepted by the community.

In the past many reuse projects overseas have failed, in spite of getting support from the potential users initially. In California many reuse projects have failed to win public acceptance though water reuse is very well accepted by Californians [54]. The general community agrees with the necessity of reusing water, but they themselves could not reuse the water. Wegner-Gwidt reviewed principles of sound and proactive communication and education programs for the community, required for the success of reuse schemes [56]. Exall et al. [56] mentioned the main goals of establishing a communication process are to (a) inform and educate the community, (b) add community input to the development, (c) raise issues early and avoid surprises, and (d) identify the project opponents and their issues. Hartley [57] produced a framework for water resources professionals to assess the community context and to public outreach, education and participation.

VI. Future Research Need

Most of the water recycling studies to date has considered only roof runoff, i.e., rainwater harvesting. Such as, Ward, Memon and Butler [58] evaluated the design of two different new-build rainwater harvesting systems using a state–of-the-art continuous simulation modelling approach. However a significant amount of research regarding stormwater harvesting and reuse has been conducted to date. Among them most has been specific to single component (among four components: drainage system, collection system, storage system or distribution system) of stormwater harvesting in a disaggregated manner. Dayaratne [9] considered only urban stormwater drainage system using a storm water drainage computer model - ILSAX in his PhD thesis. Some researchers assessed the performance of a single stormwater treatment measure like the Gully pot or Green gully, etc. For example, Memon and Butler [4] assessed the gully pot management strategies for runoff quality control using a dynamic model. Some researchers have developed models to evaluate the performance of that specific software for specific location only. For example, Lekkas et al. [5] used Aquacycle, an integrated urban water modeling for simulating water use, wastewater production and stormwater drainage of greater Athens. Some people used estimated model parameters only. Liu et al. [59] derived pollutant build-up parameters from catchment field investigations and compared that with model calibration using MIKE URBAN for three catchments in Southeast Queensland, Australia. Several studies have highlighted Geographic Information System (GIS) applications in hydrologic and hydraulic modeling.

There are still noticeable lackings in the field of stormwater modeling that covers all the major elements of a stormwater harvesting system in an integrated manner. Therefore a great potential is present for the integration of all the major components of stormwater harvesting and reuse using advanced technologies. For that purpose a DSS can integrate with stormwater model, GIS, database, evaluation tools and GUI. Therefore future model development should focus not only on GIS interfaces and integration with models, but should also include integration with a more complete management information system.

There are gaps in modeling capacity and knowledge behind the models. Government agencies and public sectors are not always very well aware of the modeling software that they are using. Though there is lots of modeling softwares available for stormwater study, but all are not properly evaluated or examined of their validity. Generally the success of a model depends on how easily it can be used and how accurate are its predictions. Some of the software is criticized by some researchers regarding the scientific foundation. However, some models are still not widely used in practice, only concerned to research laboratories. Even there is no specific technology designed for stormwater reuse and the existing stormwater harvesting and reuse practice is far ahead of research. In Australia urban catchments are mostly ungauged. It is necessary to develop regional equations to estimate model parameters of widely used computer models for the ungauged catchments. There is a lack of proper guidelines for the modeling of ungauged catchments. Moreover, despite of the presence of different guidelines and regulations of stormwater harvesting and reuse, there is still significant scope to improve this field by proper implementation of these guidelines.

Though the importance of public acceptance of a successful water reuse program is widely acknowledged, there is an obvious need of social studies to investigate the basis of public perceptions of water reuse and the psychological factors governing their decision making processes. However, concentrated research effort is required to address the gap adequately.

VII. Conclusions

Realizing the increased stress on mains water supply systems and an increasing recognition of the need to exploit stormwater for many purposes, the harvesting and reuse of stormwater is becoming an important and feasible option. For better understanding of this, implementation of proper technique is vital. Numerical modeling has, in recent times, become a popular tool for assessing the feasibility of stormwater harvesting as it simulates both the quantity and quality of stormwater. Application of numerical models covering all the hydrologic, hydraulic, water quality and water balance modules may be useful to provide insights for improved understanding of the feasibility of stormwater harvesting and reuse. Moreover the use of GIS in stormwater study is widespread due to its local data gathering effort and integration with modeling software. But for effective management of a successful stormwater harvesting project neither model nor GIS can be a central data tool. Rather incorporation of database is needed that will handle the temporal information effectively. Therefore DSS is the appropriate system that integrates all the tools from model, GIS and database. Furthermore DSS incorporatesevaluation tools and GUI together for getting a complete management practice. Despite sufficient information and technology are available regarding stormwater harvesting and reuse, but there is still some lacking in the field of integrated management of this industry covering all the major components such as collection, storage, treatment, flood protection and distribution system. Therefore, during the development of future model these considerations should be incorporated.

To estimate model parameters of ungauged catchments, development of regional equations is important, as most of the urban catchments of Australia are ungauged. There is a lack of guidelines of modeling in ungauged catchments. Moreover, implementation of present guidelines properly is required in the project of stormwater harvesting and reuse. A user of the guideline should not use specific aspects of the guidelines in isolation. Another important aspect of successful stormwater harvesting is public acceptance. Without wide public acceptance water reuse projects cannot succeed. Therefore, social study should require investigating public sentiment before implementation of a stormwater harvesting project.

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