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UNDERSTANDING THE ROLE OF LAND USE IN URBAN STORMWATER QUALITY MANAGEMENT

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Abstract

Urbanisation significantly impacts on water environments with increased runoff and the degradation of water quality. The management of quantity impacts are straight forward, but quality impacts are far more complex. Current approaches to safeguard water quality are largely ineffective and guided by entrenched misconceptions with a primary focus on ‘end-of-pipe’ solutions. The outcomes of a research study presented in the paper, which investigated relationships between water quality and six different land uses offer practical guidance in the planning of future urban developments. In terms of safeguarding water quality, high density residential development which results in a relatively smaller footprint would be the preferred option. The research study outcomes bring into question a number of fundamental concepts and misconceptions routinely accepted in stormwater quality management. The research findings confirmed the need to move beyond customary structural measures and identified the key role that urban planning can play in safeguarding urban water environments.

Keywords: multivariate analysis, stormwater quality management, urban water quality, water quality impacts

1. Introduction

1.1 Background

Urban expansion transforms local environments and in the context of effective urban resource planning and management, the recognition of the impacts of urbanisation on the water environment is among the most crucial. The significance stems from the fact that water environments are greatly valued in urban areas as environmental, aesthetic and recreational resources and hence are important community assets. Any type of activity in a catchment that changes the existing land use will have a direct impact on the quantity and quality characteristics of the water environment.

Land use modifications associated with urbanisation such as the removal of vegetation, replacement of previously pervious areas with impervious surfaces and drainage channel modifications invariably result in changes to the characteristics of the surface runoff hydrograph. Consequently the hydrologic behaviour of a catchment and in turn the streamflow regime undergoes significant changes. The hydrologic changes that urban catchments commonly exhibit are, increased runoff peak, runoff volume and reduced time to peak (ASCE, 1975; Codner et al., 1988; Mein and Goyen, 1988). Urbanisation also has a profound influence on the quality of stormwater runoff. These consequences are due to the introduction of pollutants of physical, chemical and biological origin resulting from various anthropogenic activities common to urban areas. As researchers such as Owens and Walling (2002), Sartor and Boyd (1972) and Wahl et al. (1997) have identified, urban stormwater runoff constitutes the primary transport mechanism that introduces non-point source pollutants to receptor areas.

These contaminants will detrimentally impact on aquatic organisms and alter the characteristics of the ecosystem. This results in a water body which is fundamentally changed from its natural state (Hall and Ellis, 1985; House et al., 1993; Wahl et al., 1997). The pollutant impact and ‘shock load’ associated with stormwater runoff can be significantly higher than secondary treated domestic sewage effluent (House et al., 1993; Novotny et al., 1985). In summary, the deterioration of water quality, degradation of stream habitats, and increase in flooding, are among the most tangible of the resulting detrimental quantity and quality impacts of urbanisation.

1.2. The Management Dilemma

The management of quantity impacts of stormwater runoff is relatively straight forward. The common approach is the provision of various physical measures such as detention/retention basins, wetlands or features such as porous pavements to retain part of the runoff volume and/or attenuate the runoff hydrograph. The primary objective of these measures is to replicate the pre-urbanisation runoff hydrograph. Under appropriate conditions, these structural measures have proven to be effective.

Unfortunately, the management of quality impacts due to urbanisation are far more complex. The current state of knowledge with regards to the process kinetics of pollutant build-up and wash-off is extremely limited. The generation and transport of pollution in urban systems during a storm event is multifaceted as it concerns many media, space and time scales (Ahyerre et. al., 1998). These processes are influenced by a range of factors which do not lend themselves to simple mathematical modelling and the simplistic modelling approaches commonly adopted can lead to gross error (Barbe et al., 1996; Irish et al., 1998).

These uncertainties and limited knowledge can be ascribed to the fact that the current focus on urban water quality is of relatively recent origin. It is a paradigm shift from the sole focus in the past on quantity issues for flood mitigation. However the techniques and approaches adopted are strongly rooted in quantity research undertaken in the past. This applies not only to modelling philosophies and water quality models currently available, but also to the conducting of research and data analysis There is an undue reliance on physical processes and the neglect of important chemical and biological processes in describing various stormwater associated phenomena.

Therefore in the absence of appropriate guidance, current approaches to safeguard water quality are similarly guided by a primary focus on ‘end-of-pipe’ solutions. The management of water quality impacts do not necessarily lend themselves to simple solutions. The provision of appropriate facilities would depend on the targeted pollutants. As an example, using a gross pollutant trap, the removal of pollutants such as litter is relatively simple. However the removal of other pollutants poses a more challenging task. Wetlands are a common measure used for dealing with stormwater quality. However these have significant limitations. Due to the land area needed, wetlands can only afford to treat relatively small volumes of stormwater. Additionally, their efficiency in quality improvement is not completely proven, particularly the removal of very fine sediments and dissolved nutrients. Furthermore, adequate guidelines for weed removal and maintenance is generally not available.

The removal of sediments in stormwater is another commonly adopted management measure. However it is important to take cognisance of the size range of sediments removed by any treatment measure. Suspended solids act as a mobile substrate for pollutants such as heavy metals and polycyclic aromatic hydrocarbons (PAHs) (Hoffman et al., 1982; Sartor and Boyd, 1972; Shinya et al., 2000; Tai, 1991). As such there is no doubt as to the importance of the removal of suspended solids from urban stormwater runoff. However at the same time it is important that the facilities provided are capable of removing the critical size range of sediments which would be carrying a significant pollutant load. Research has shown that due to their physico-chemical characteristics, the finer particulates are more efficient in the adsorption of pollutants and hence will carry a relatively higher pollutant concentration (Andral, 1999; Hoffman et al., 1982; Roger et al., 1998; Sartor and Boyd, 1972).

However, outcomes from some studies have noted that the fraction of fine particulates in runoff can be small, and as such the total pollutant load would be smaller when compared to the load carried by the coarser particulates (Marsalek et al., 1997). Therefore it has been argued that it is the load rather than the concentration which is of importance and hence the focus should be on the removal of the coarser fraction. Contrary to these findings, other studies have reported a larger fraction of fine particulates (Andral, 1999; Pechacek, 1994). The particle size of sediments is a function of the catchment characteristics. Hence these contradictory findings confirm that catchment characteristics play the most significant role in urban stormwater runoff quality. Therefore any treatment measures adopted should take the relevant catchment characteristics into consideration.

1.3. The First Flush Phenomenon

The ‘first flush’ concept is another issue which is questionable in relation to urban water quality management strategies currently adopted. The ‘first flush’ relates to the initial portion of the runoff being more polluted than the remainder due to the washout of deposited pollutants by rainfall. There is little conclusive evidence from past research studies to prove the effectiveness of this strategy. As reported by numerous researchers, the first flush has been noted as an important and distinctive phenomenon within pollutant wash-off. It produces higher pollutant concentrations early in the runoff event and a concentration peak preceding the peak flow (Deletic, 1998). This has significant economic implications in relation to the management and treatment of urban stormwater runoff. The economic significance stems from the fact that structural measures for water quality control such as detention/retention basins are often designed for the initial component of urban runoff.

Hall and Ellis (1985) have claimed that the first flush phenomenon is over emphasised and only 60–80% of storms exhibit an early flushing regime. As Deletic (1998) has pointed out, in view of the diverse definitions, varying sampling strategies and data collection methods, it is difficult to compare results from different studies. This could possibly explain the differences in reported observations in relation to the occurrence of the first flush.

The qualitative descriptions commonly found in literature cannot be used as an appropriate basis to plan structural pollutant abatement measures. In understanding the first flush, the major difficulty arises with respect to defining this phenomenon in a quantitative manner. As Bertrand-Krajewski et al., (1998) and Saget et al., (1996) have pointed out, the problem stems from the fact that the ‘initial component of runoff’ which carries the first flush is never precisely defined. This is despite its commonly reported occurrence in qualitative terms. A mere increase in pollutant concentration at the beginning of a storm cannot be interpreted in a quantitative manner. In the context of stormwater pollution management, it is the pollutant load rather than pollutant concentration that is of significance. Due to the corresponding runoff volume being low and despite the increase in pollutant concentration, the pollutant load during the initial phase of runoff could be relatively low when compared to the overall load carried by the runoff event, (Barrett et al., 1998). The above findings underline the need to move beyond the dependency on customary structural measures and end-of-pipe solutions.

1.4. Correlating land use with water quality

A common objective of most urban water quality studies has been to strive to relate land use to pollutant loadings. However the outcomes to-date has been far from conclusive, thus making it difficult to identify cause-effect relationships (Hall and Anderson, 1986; Lopes et al., 1995; Parker et al., 2000; Sartor and Boyd, 1972). The major failure has been the inability to derive statistically significant relationships even though qualitative relationships are generally evident. This could be partially attributed to the procedures adopted for data analysis such as the sole dependency on univariate statistical analysis and its inherent limitations in being able to take into consideration multiple variables.

2. Materials and Methods

2.1 Research project

An ongoing water quality research project was established in 1999, based in Gold Coast, in the Southeast region of Queensland State, Australia. This project has undertaken an in-depth investigation of pollutant wash-off by analysing the hydrological and water quality data from three primary catchments and three subcatchments. The research study was formulated to investigate the relationships between water quality and urban form. As the fastest developing region in Australia, the study outcomes are expected to offer Gold Coast City Council practical guidance in the planning of future developments. It will assist in the formulation of management strategies for the protection of significant ecosystems in the region including World Heritage sites, important water resources and Ramsar wetland sites.

The study areas were selected so as to ensure that there was uniformity in the geological, topographical and climatic variables which could possibly influence the water quality characteristics. The three main catchments are characterised by the same geology based on the Neranleigh-Fernvale metasediments and similar predominant soil types, mainly Kurosols. However they have differing forms of land development and housing density; ranging from predominantly forested in the upper Bonogin Valley (Bonogin), to rural acreage-residential (un-sewered) in the lower Bonogin Valley (Hardy), to mixed urban development (sewered) in Highland Park catchment. Three smaller subcatchments within the Highland Park catchment were identified for more detailed investigations into effects of increasing urban density on water quality. These subcatchments are a tenement townhouse development of around 60 properties (Alextown), a duplex housing development with around 20 dual occupancy residences (Gumbeel) and a high-socio-economic single detached-dwelling area (Birdlife). For each of the six gauged catchments described above, stream flow samples were collected for rainfall events and during low flow conditions. The samples were analysed for a range of water quality parameters. The data thus obtained was analysed using univariate and multivariate statistical analysis to evaluate the influence of urban form on stormwater quality.

The locations of the study areas are shown in Figures 1 and 2, whilst Table 1 provides a summary of the relevant characteristics of each area.

Insert Figure 1, Figures 2, Table 1

2.2 Sample collection and testing

Automatic monitoring stations were established at the outlet of each area. Each station was equipped with an automatic event sampler to augment grab samples taken during low flow conditions. The automatic monitoring stations record streamflow, and water quality parameters including pH, electrical conductivity (EC), temperature and dissolved oxygen concentration (DO). Event samples collected by automatic sampling devices and the grab samples taken during low flow conditions were analysed for total organic carbon (TOC), suspended solids (SS), total nitrogen (TN) and total phosphorus (TP). Sample collection commenced from July 1999 for the three main catchments, and from December 2001, for the three subcatchments. Sample testing was undertaken according to the test methods specified in APHA (1999).

3. Data Analysis

3.1 Univariate data analysis

A series of univariate statistical analysis was undertaken when a block of data became available. Rahman et al. (2002) developed of a set of preliminary predictive equations based on the data from July 1999 to July 2001 for the three primary catchments relating key pollutant parameters and rainfall characteristics. For Bonogin, an equation was developed to predict TP from TSS. This equation had a high coefficient of determination (95%) and a relatively small standard error of estimate (25%). Unfortunately in the case of Hardy and Highland Park catchments, the various predictive equations developed did not reflect the same degree of statistical accuracy. However most importantly, the study by Rahman et al. (2002) highlighted the importance of developing a deeper understanding of the interactions and linkages between influential parameters.

Table 2 gives the mean and standard deviation (SD) for all the study areas from July 1999 to about July 2003. These data are primarily samples of storm-event flows with the number of data points analysed for each site given in parenthesis. In the case of the Bonogin catchment, the number of data points is only 50% of that for the other two primary catchments even though data monitoring for all three catchment commenced at the same time. This difference between the catchments is due to the forested land use which tends to maintain higher soil infiltration and storage capacity. The catchment does not commonly generate runoff for low intensity or short duration rainfall events.

Insert Table 2

Based on the data given in Table 2, the following can be discerned

- For the three primary catchments, other than for TOC parameter values, stormwater runoff from the urban catchment displays the highest standard deviation for all the other parameters. This indicates a high variability of stormwater quality from the urban catchment thus underlying the difficulties in developing urban water quality predictive models.
- Runoff from the Highland Park catchment also exhibits the highest concentration values which illustrates the polluted nature of runoff as urbanisation increases.
- The high concentration and variability of TOC values for Bonogin catchment can be attributed to the extensive tree canopy. The Hardy catchment similarly has a high tree canopy. The issue is discussed further in Section 3.2.
- Among the three subcatchments, stormwater runoff from Birdlife subcatchment exhibits the highest concentration and variability of pollutants other than for TN.
- Runoff from the Gumbeel subcatchment has a higher TN concentration and variability when compared to Birdlife. This high-density residential development has only a very limited garden/open space and is maintained with great care. It is postulated that there would be high usage of fertiliser considering the condition of the lawn.

3.2 Multivariate data analysis

Subsequent to the univariate study, multivariate techniques were applied to identify linkages between various pollutant parameters and correlations with land use. Essentially, principal component analysis (PCA) was used for pattern recognition. PCA is a multivariate statistical data analysis technique which reduces a set of raw data into a number of principal components which retain the most variance within the original data in order to identify possible patterns or clusters between objects and variables. Detailed descriptions of PCA can be found elsewhere (Adams, 1995; Kokot et al., 1998; Massart et al., 1988). PCA has been used extensively for various applications related to water quality. As examples, Wunderlin et al. (2001) used PCA for the evaluation of spatial and temporal variations in river water quality and Marengo et al. (1995) to characterise water collected from a lagoon as a function of seasonality and sampling site and for the identification of significant discriminatory factors. Hamers et al. (2003) employed PCA to study pesticide composition and toxic potency of the mix of pollutants in rainwater and Librando et al. (1995), for the analysis of micropollutants in marine waters. Similarly Vazquez et al. (2003) used PCA to evaluate factors influencing the ionic composition of rainwater in a region in NW Spain.

Matlab Ver6.5 Release 13 software (MathWorks Inc. 2002), was used for undertaking the multivariate data analysis. This software was selected due to its versatility, ease of use and superior data handling capabilities. In the PCA undertaken, the water quality concentration data as mg/L was arranged into a matrix using the software for each study area. The columns in the matrix that was developed defined the variables and the rows, the sample measurement. The raw data was initially subjected to pre-treatment to remove ‘noise’ which may interfere in the analysis (Adams, 1995, Kokot et al., 1998). Firstly, the data was log transformed to reduce data heterogeneity. Following this, the transformed data was column-centred (column-means subtracted from each element in their respective columns) and standardised (individual column values divided by the column standard deviations). PCA was undertaken on the transformed data for pattern recognition and for the identification of correlations between selected variables.

Using the principal components PC1 which described the largest data variance and PC2, the next largest amount of data variance, it was possible to develop Biplots for the individual study areas as shown in Figures 3 – 8. In the urbanised catchments (Figure 4 – 8) the data was found to form into a series of clusters. This is most evident in Figure 4, the rural acreage residential catchment, and as the intensity of urbanisation increases this effect is less pronounced. These clusters can be related to rainfall intensity. It is postulated that as the level of urbanisation increase, even low intensity rainfall would produce runoff and hence pollutant loadings. However in the case of catchments with significant extents of pervious area such as Hardy catchment, the rainfall intensity would have a significant influence on the fraction of rainfall converted to runoff unlike for a highly urbanised catchment. The principal component analysis of the physico-chemical data set resulted in most of the data variance being contained in the first two components. The angle between loading vectors is significant as the degree of correlation between individual parameters is inversely related to it. Hence as the angle reduces, the degree of correlation increases. Vectors situated closely together represent variables that are highly correlated while orthogonal vectors represent variables that are uncorrelated. The conclusions derived from the PCA is given below.

Insert Figures 3 – 8.

Bonogin (forested) – Figure 3

- As TP and TN are strongly correlated with SS, it can be surmised that most of the nutrients are particulates.
- Some correlation between TOC and SS. As the catchment is forested, it is postulated that the particulate component of TOC is due to leaf litter.
- The above observations are understandable, considering the fact that the catchment is forested.
- From a management perspective, structural stormwater improvement measures such as detention basins or sediment traps would be effective in removing most of the pollutants in the water. Similarly stormwater wetlands too, would be of limited effectiveness as discussed in Section 1.2 above.

Hardy (rural residential) – Figure 4

- TN not correlated with SS or TOC. Hence TN is primarily in dissolved form.
- SS and TOC are only weakly correlated with TP or with each other.
- Hence most TOC and TP would be in dissolved form. TOC would be primarily in the form of DOC.
- It is hypothesised that there is leaching of nutrients from the on-site wastewater treatment systems in the area. This entire catchment is not serviced by centralised sewage collection.

- Additionally most SS would be inorganic particles. This could be possibly due to the erosion of road edges due to surface runoff. The roads do not have kerb and channelling and in most places are not provided with grass swales.
- From a management perspective, structural stormwater improvement measures such as detention basins or sediment traps will only be effective in removing SS but not the other pollutants such as TN, TP and oxygen demanding material. Similarly stormwater wetlands too, would be of limited effectiveness as discussed in Section 1.2 above.

Highland Park (mixed use urban) – Figure 5

- TN and TP closely correlated. However considering the three gauged subcatchments within this catchment as shown in Figures 6, 7 and 8 and discussed below, similar relationships are not uniform. Hence it could be surmised that these types of relationships are a characteristic of the combination of the different subcatchment areas, the different management practices and spatial distribution of impervious areas.
- TN and TP have some correlation with SS. Therefore an appreciable proportion of the nutrients would be in particulate form.
- TOC is significantly correlated with SS. Hence an appreciable proportion of TOC would be in particulate form.
- It could be hypothesised that an appreciable proportion of the pollutants such as TOC, TN and TP could be from leaf litter or grass clippings.

- From a management perspective, structural stormwater improvement measures such as detention basins, sediment traps or wetlands could be partially effective in removing SS, TN, TP and oxygen demanding material.

Alextown (townhouse development) – Figure 6

- TN and TP only weakly correlated with each other.
- TN, TP, TOC and SS are not correlated with each other.
- TN, TP and TOC would be in dissolved form but independent of each other. TOC would be primarily in the form of DOC.
- From a management perspective, structural stormwater improvement measures such as detention basins or sediment traps will only be effective in removing SS but not the other pollutants such as TN, TP and oxygen demanding material. Similarly stormwater wetlands too, would be of limited effectiveness as discussed in Section 1.2 above.

Gumbeel (duplex development with about 70% impervious area) – Figure 7

- TN and TP are closely correlated with each other but not with SS.
- Hence both TN and TP must be in dissolved form.
- There is weak correlation between SS and TOC. TOC would be primarily in the form of DOC.
- SS would be primarily in inorganic form.
- From a management perspective, structural stormwater improvement measures such as detention basins or sediment traps will only be effective in removing SS but not the other pollutants such as TN, TP and oxygen demanding material. Similarly

stormwater wetlands too, would be of limited effectiveness as discussed in Section 1.2 above.

Birdlife (detached houses in large blocks) – Figure 8

- TN and TOC not correlated with SS.
- TP only very weakly correlated with SS.
- Hence, TN, TP and TOC would be primarily in dissolved form.
- From a management perspective, structural stormwater improvement measures such as detention basins or sediment traps will only be effective in removing SS but not the other pollutants such as TN, TP and oxygen demanding material. Similarly stormwater wetlands too, would be of limited effectiveness as discussed in Section 1.2 above.

4. Discussion

Comparing the results obtained for the Highland Park catchment (the mixed use urban catchment) with the three urban subcatchments, there is very little similarity. This is also the case among the different subcatchments. This can be attributed to the fact that the land use and land cover characteristics, the spatial distribution of impervious areas and the management practices of the three subcatchments are appreciably different and the results obtained would reflect these differences. On the other hand, in the case of the Highland Park catchment, in addition to having the three subcatchments contained within it, there are also significant extents of other impervious and pervious areas.

Hence the results obtained, would be an averaging of the pollution generated from all these land cover characteristics.

Also, even though the percentage of impervious area for Alextown and Gumbeel are similar, there are differences in the results of the data analysis between the two subcatchments. A number of reasons could be attributed to this situation. Firstly, the spatial distribution of impervious area in the two subcatchments are different. This would have significant influence on the time and velocity of travel of surface runoff and hence the pollutant load. Secondly, the fraction of road surface within the impervious area is higher for Alextown when compared to Gumbeel. As researchers such as Bannerman et al. (1993) have pointed out, street surfaces are the single most important source of urban water pollution. Secondly, the pervious area in Alextown act as a common area for the residents and maintained by the caretaker. However in the case of Gumbeel, each residence has an individual small garden with varying degree and style of management and care.

Considering the three urbanised subareas, most of the organic matter is in the form of dissolved organic carbon (DOC). Organic carbon or oxygen demanding materials generally constitute a major pollutant in urban stormwater runoff. The common impact of organic matter is the reduction in dissolved oxygen in water due to microbial oxidation. However the more serious impact of dissolved organic matter is insidious. Organic matter of size less than <0.45μm, commonly referred to as dissolved organic carbon has a significant impact on water quality. It absorbs and reacts with sunlight energy, complexes metals, provides an energy source for microorganisms and associates with hydrophobic substances such as hydrocarbons (Westerhoff and Anning, 2000). It plays a major role in the transport and bioavailability of metals and hydrocarbons through complexation reactions. Furthermore, organic carbon adsorbed on suspended solid particles increases their sorption capacity for combining with hydrophobic organic substances and some heavy metals such as lead and zinc (Parks and Baker, 1997; Roger et al., 1998). Though these characteristics may be considered beneficial aspects, the organic matter is liable to microbial decomposition, thereby returning the pollutants back to the dissolved phase at a later stage of runoff flow.

Additionally in the subareas, other common pollutants such as nutrients (nitrogen and phosphorus) are also present in dissolved form. Therefore under these circumstances, commonly adopted structural measures for urban water quality improvement such as detention basins and sediment traps will only be effective in removing suspended solids but not the other pollutants. Similarly stormwater wetlands too may not be particularly effective as their ability to remove dissolved nutrients and other pollutants is limited.

Comparing the three different urban forms as represented by the different subareas, Birdlife has the most adverse footprint. This is based on the concentration of various pollutants, their high variability and physico-chemical form. Considering the nature of the different urban developments, it could be surmised that detached houses contribute a greater pollutant load than multi-family dwelling units. It is probable that these pollutants are being generated from the landscaped gardens and the relatively greater extent of road surface area.

In the case of the three primary catchments, the results obtained are not altogether surprising. However with regards to Highland Park catchment, the conclusions from the multivariate analysis that TOC, TN and TP had a reasonable correlation with SS could be misleading. It should be noted that this mixed use urban catchment has appreciable open space and vegetation cover, with only 55% impervious cover. It is also important to note that the concentration of TOC is much higher (by 38%) than the SS concentration. Therefore it could be surmised that there is a significant concentration of DOC. It should also be borne in mind that the three subareas studied are located within this larger catchment. The problems noted within these areas do not necessarily recede at the outlet of a larger catchment. It could be surmised that the contribution of pollutants from other source areas are influencing the results derived at the catchment outlet.

Many factors affect the quality of stormwater runoff with land use being the most important. Though numerous research studies have attempted to relate land use to pollutant loadings, the outcomes reported can be conflicting (Hall and Anderson, 1986; Lopes et al., 1995; Parker et al., 2000; Sartor and Boyd, 1972). This is due to the reliance on physical processes and the neglect of important chemical processes in describing various stormwater associated phenomena. There is no question that the urban environment is adversely affected by a variety of anthropogenic activities which introduces numerous pollutants to the environment. However major uncertainties arise in efforts to articulate the process kinetics of pollutant generation, transmission and dispersion.

The outcomes from this study bring into question a number of fundamental concepts and misconceptions routinely accepted in stormwater quality management. The fact that characteristics and chemical composition of primary stormwater pollutants are influenced by the urban form would mean that the effectiveness of structural measures would not be universal. The common management technique of dealing with suspended materials as a primary treatment measure for urban stormwater quality would have limited success as other pollutants are not necessarily in suspended form with a significant proportion being in dissolved form.

The above findings underline the need to move beyond the dependency on customary structural measures and end-of-pipe solutions and the key role that urban planning can play in safeguarding urban water environments. The results obtained in effect means that the mere provision of standard structural measures is not necessarily effective in removing water quality pollutants per se. Any structural measures to be adopted should depend on targeted pollutants and management strategies adopted should take into consideration the rainfall, runoff and physical characteristics of the area. The univariate and multivariate statistical data analysis undertaken found that among the different urban forms, stormwater runoff from the area with detached housing in large suburban blocks exhibited the highest concentration and variability of pollutants. Rural residential on large blocks were only marginally better. It could be concluded that in terms of safeguarding water quality, high density residential development which results in a relatively smaller footprint should be the preferred option.

5. Conclusions

Thorough data analysis is essential prior to modelling catchments and their behaviour with a view to improving stormwater quality. This paper identifies appreciable insights into non-urban, urbanising and urban catchments in Southeast Queensland, Australia. The common management technique of dealing with suspended materials as a primary treatment for urban stormwater quality is shown to be ineffective as SS in most occasions is not correlated with TN, TP or TOC. Much of the pollution is moving in dissolved form, is more bio-available and is therefore more likely to cause pollution in receiving waters. It could well be that this condition is linked to the climatic and rainfall conditions experienced in the study region which significantly influences pollutant composition, build-up and wash-off. It is important that predictive models developed has the capacity to take these characteristics into consideration.

Based on the comprehensive study into correlating water quality to urban form, the important role that urban planning can play in safeguarding urban water environments was confirmed. High density urban development which results in a relatively smaller footprint should be the preferred option. The study outcomes clearly confirmed the need to dispel myths in relation to urban water quality. The dependency on generic structural measures for urban water quality improvement was found to be of questionable value. It is important that any structural measures to be adopted are specifically focussed towards the removal of targeted pollutants. Secondly, it is important to take into consideration the climatic and physical characteristics of the catchment area.

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Figure 1. Locations of main catchments

Figure 2. Locations of the urban subcatchments

Figure 3. Biplot for Bonogin

Figure 4. Biplot for Hardy

Figure 5. Biplot for Highland Park

Figure 6. Biplot for Alextown

Figure 7. Biplot for Gumbeel

Figure 8. Biplot for Birdlife

Table 1
Characteristics of selected study areas

Study area	Extent ha	Land Cover Impervious area (buildings, roads)	Pervious area (forest, grassland)
Forest catchment – Upper Bonogin Valley (Bonogin)	647	20%	98%
Rural acreage residential catchment (Hardy)	2 726	9%	91%
Urban Residential catchment (Highland Park)	161.8	55%	45%
Townhouses – Alextown subcatchments	2.2	70%	30%
Duplex housing – Gumbeel subcatchments	0.8	70%	30%
Detached housing – Birdlife subcatchments	8.1	47%	53%

Table 2
Water quality data analysis

Study area		Parameter					
		pH	EC µS/cm	SS mg/L	TN mg/L	TP mg/L	TOC mg/L
Bonogin	mean	6.9	88.6	80.0	2.0	0.1	187.3
(56)	SD	0.3	102.4	121.6	3.3	0.2	714.7
Hardy	mean	6.9	87.9	94.4	2.0	0.1	189.8
(116)	SD	0.3	104.2	108.8	3.3	0.1	779.7
Highland Park	mean	7.1	263.1	146.7	3.6	0.2	134.4
(111)	SD	0.5	246.0	127.7	6.0	0.3	597.7
Alextown	mean	6.8	101.6	156.4	2.0	0.4	13.2
(50)	SD	0.3	57.3	171.4	2.0	0.5	7.6
Gumbeel	mean	6.8	104.0	69.5	2.5	0.7	11.0
(45)	SD	0.4	70.0	159.2	3.6	0.7	10.7
Birdlife	mean	7.2	163.2	356.7	1.9	0.8	15.2
(58)	SD	0.8	83.6	341.2	2.9	1.2	10.7

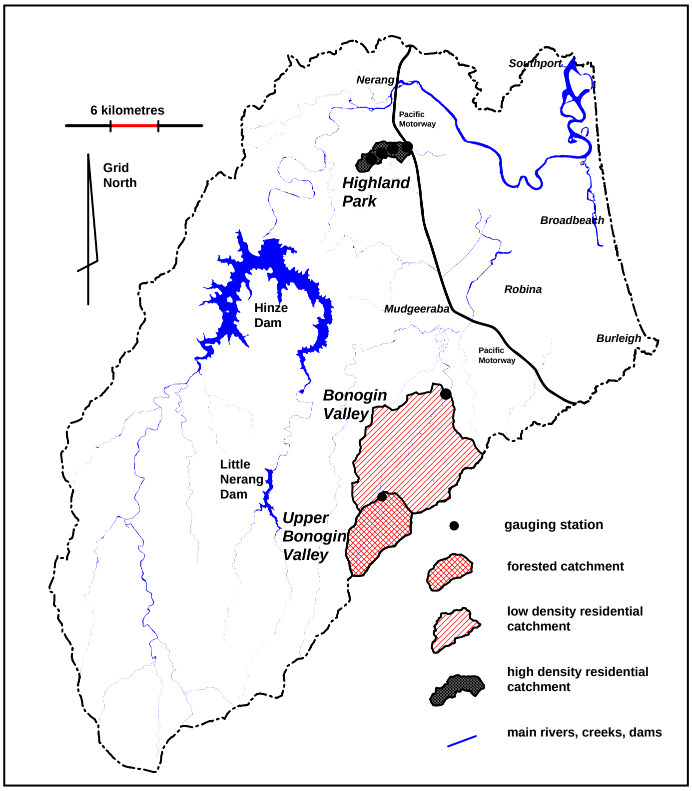

Figure 1. Locations of main catchments

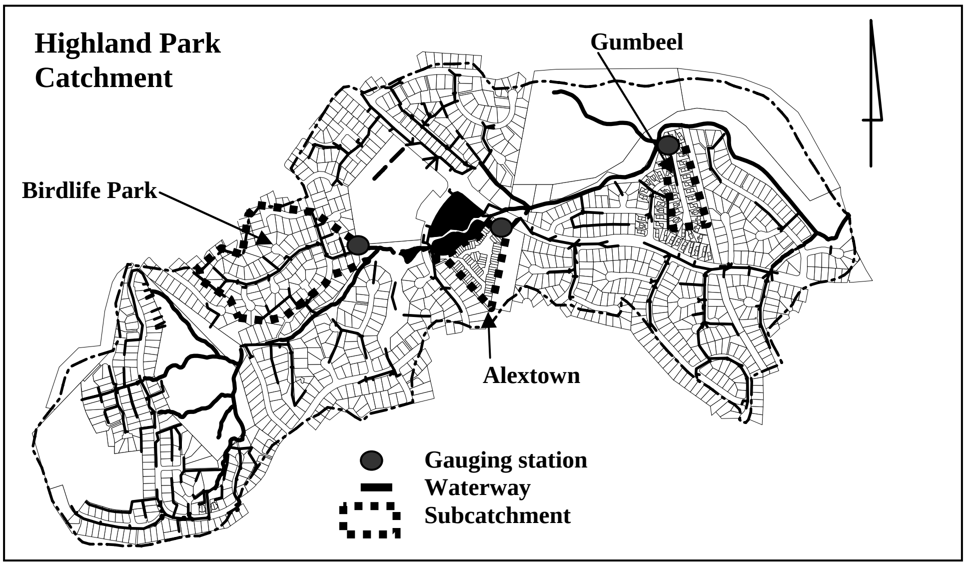

Figure 2. Locations of the urban subcatchments

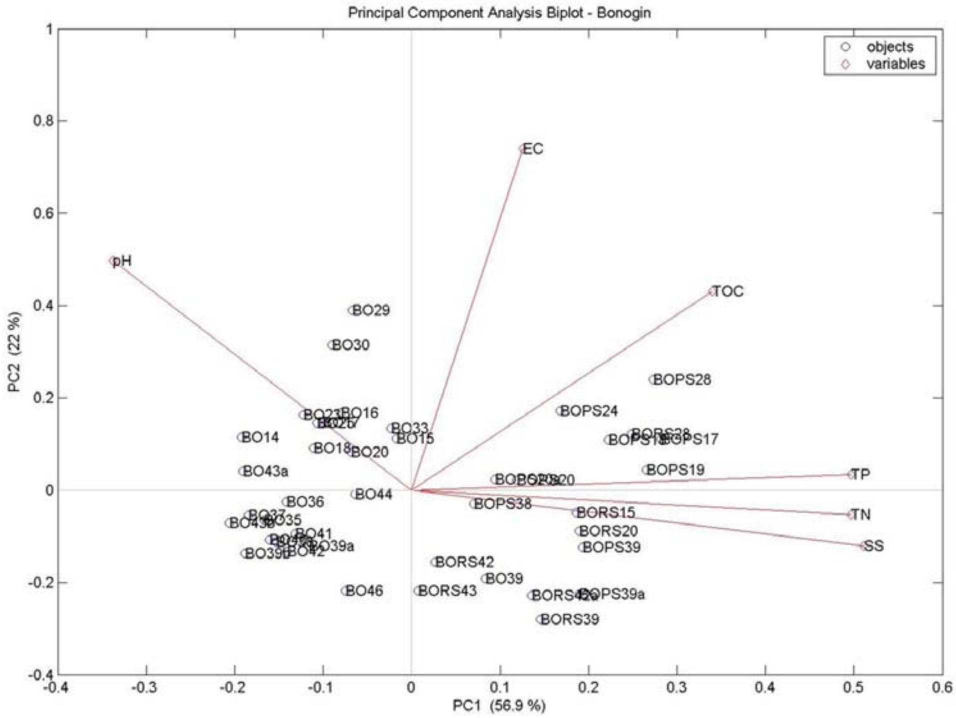

Figure 3. Biplot for Bonogin

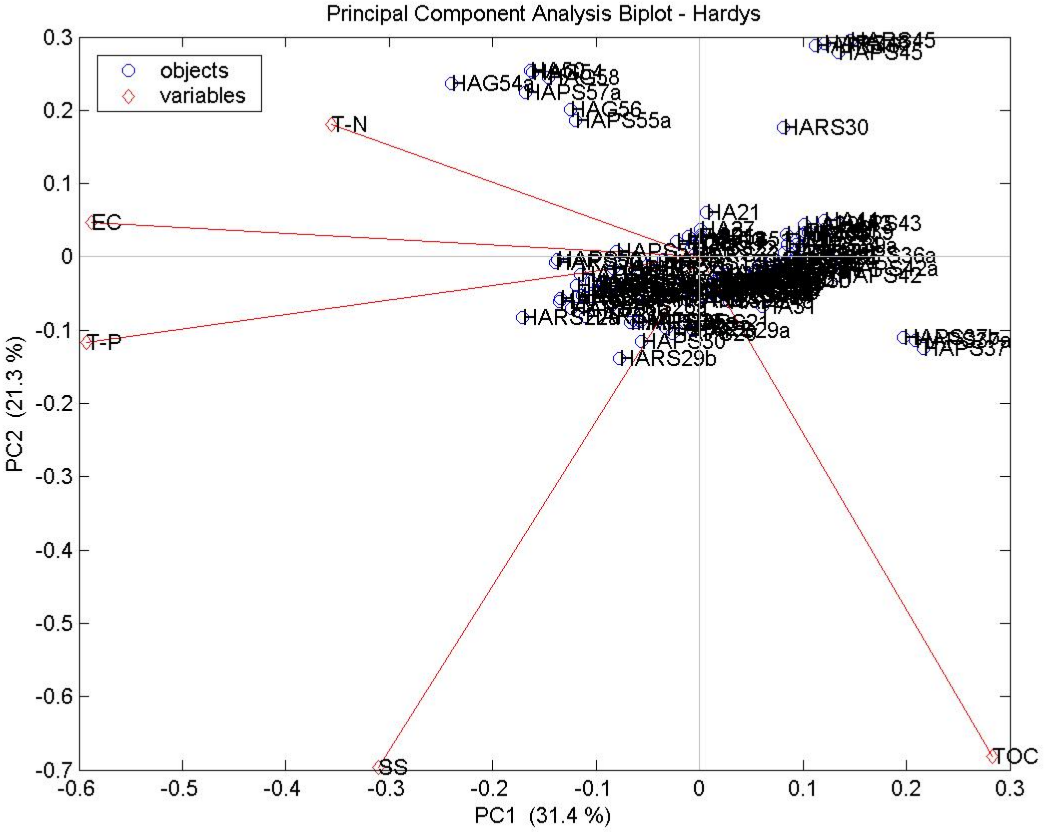

Figure 4. Biplot for Hardy

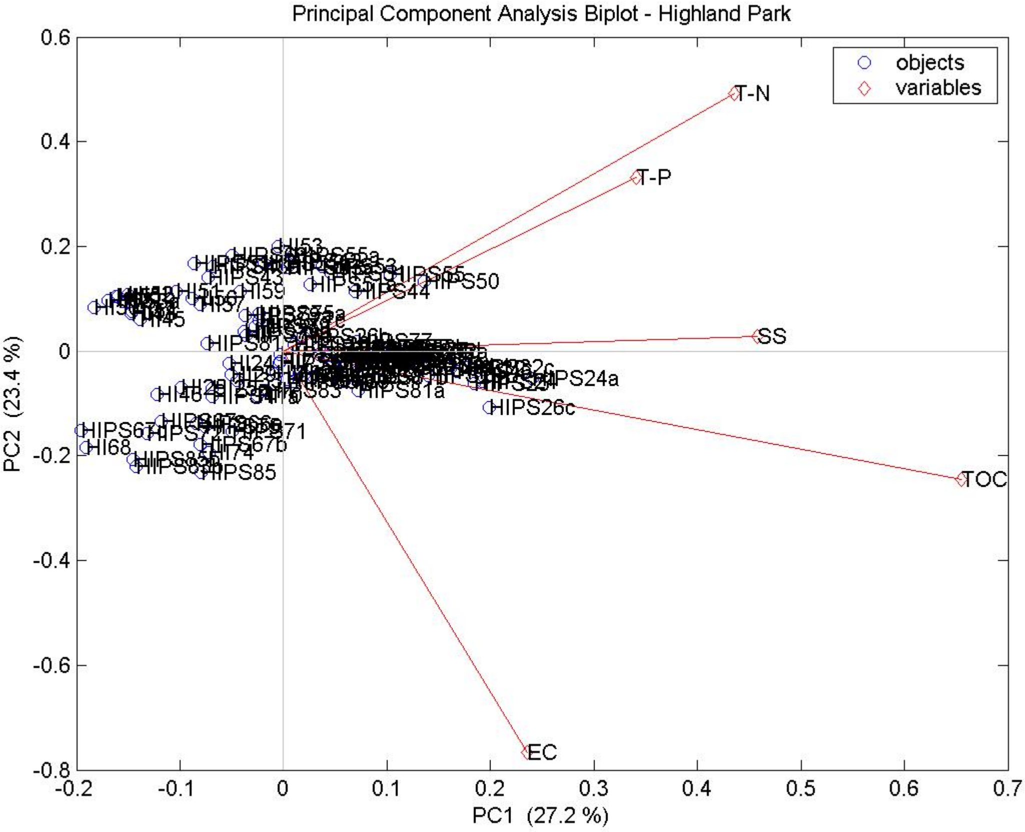

Figure 5. Biplot for Highland Park

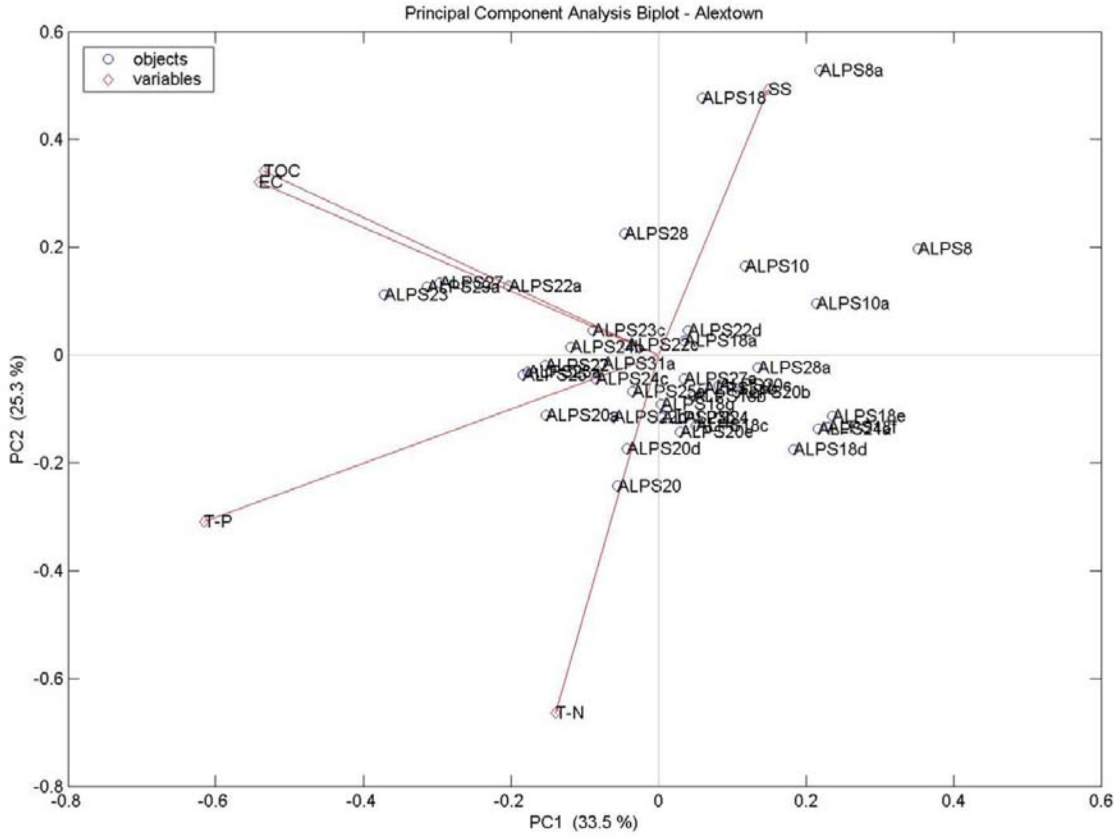

Figure 6. Biplot for Alextown

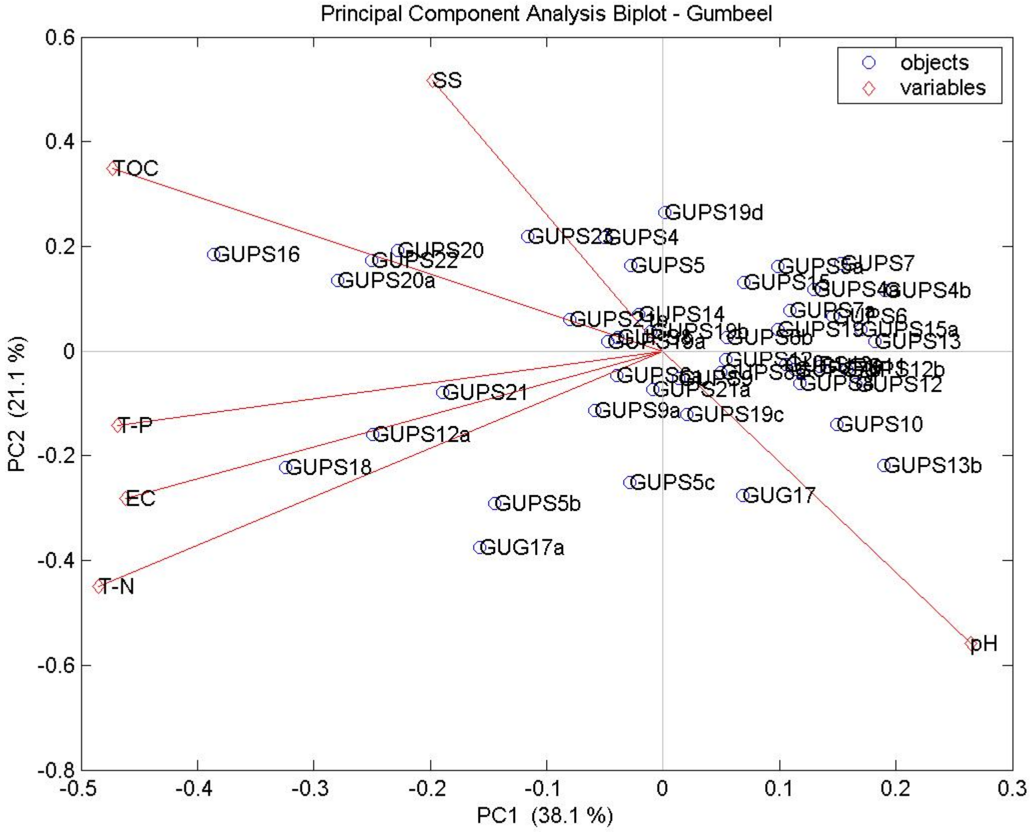

Figure 7. Biplot for Gumbeel

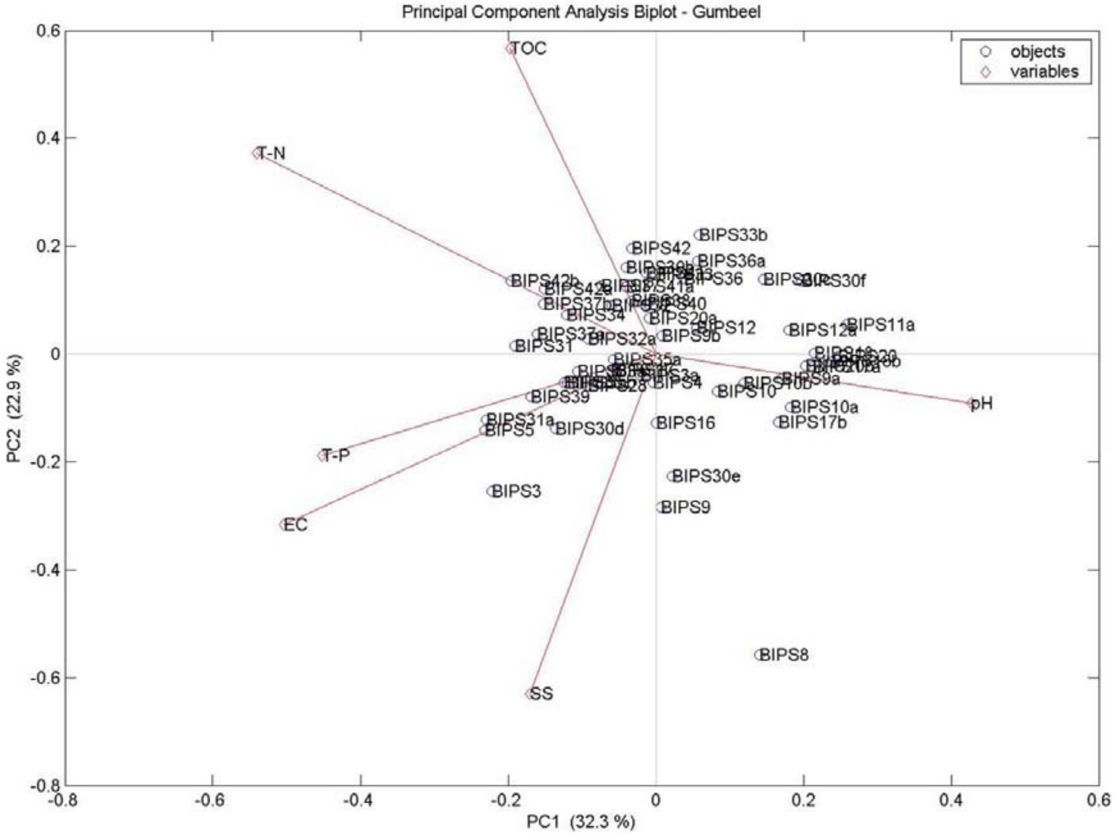

Figure 8. Biplot for Birdlife