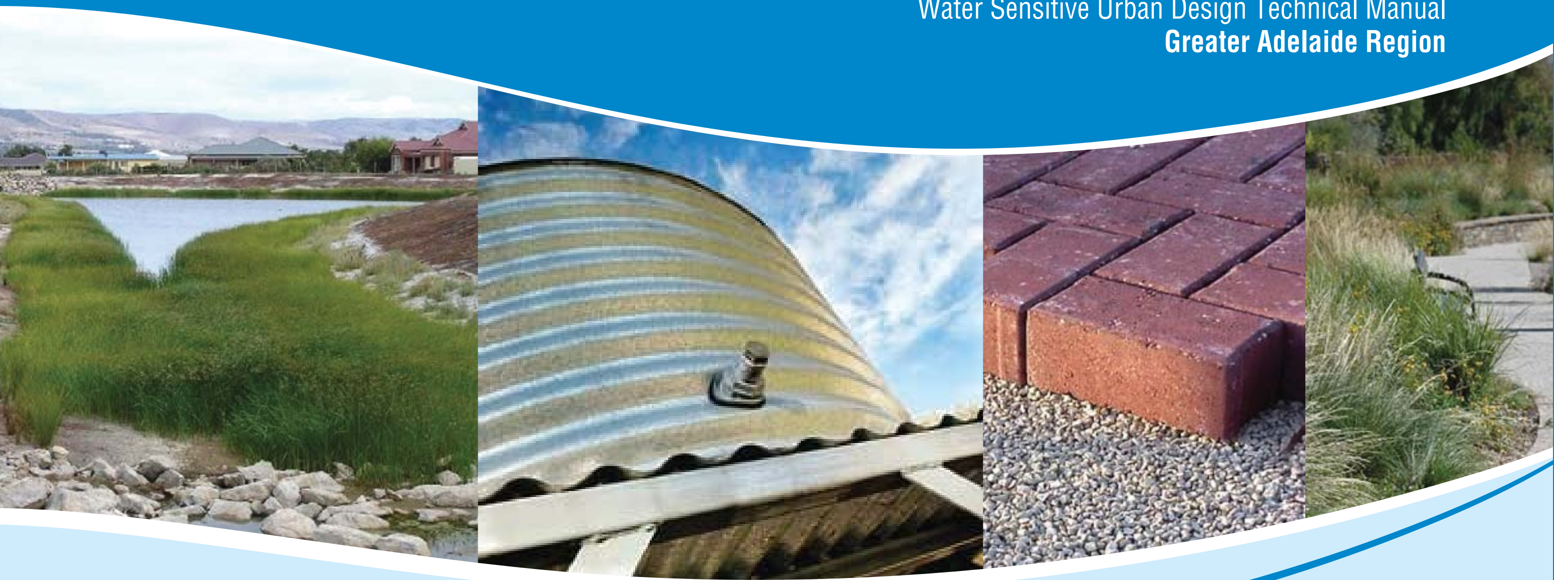
December 2010

Chapter 15

Modelling Process and Tools

Water Sensitive Urban Design Technical Manual
Greater Adelaide Region



Government of South Australia

Australian Government
Department of the Environment, Water, Heritage and the Arts

Securing tomorrow's water today.

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Water Sensitive Urban Design

Water Sensitive Urban Design (WSUD) is an approach to urban planning and design that integrates the management of the total water cycle into the urban development process. It includes:

- Integrated management of groundwater, surface runoff (including stormwater), drinking water and wastewater to protect water related environmental, recreational and cultural values;
- Storage, treatment and beneficial use of runoff;
- Treatment and reuse of wastewater;
- Using vegetation for treatment purposes, water efficient landscaping and enhancing biodiversity; and
- Utilising water saving measures within and outside domestic, commercial, industrial and institutional premises to minimise requirements for drinking and non drinking water supplies.

Therefore, WSUD incorporates all water resources, including surface water, groundwater, urban and roof runoff and wastewater.

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The project partners gratefully acknowledge all persons and organisations that provided comments, suggestions and photographic material.

In particular, it is acknowledged that material was sourced and adapted from existing documents locally and interstate.

Overall Project Management

Christine Lloyd (Department of Planning and Local Government)

Steering Committee

A group of local government, industry and agency representatives provided input and feedback during preparation of the Technical Manual. This group included representatives from:

- Adelaide and Mt Lofty Ranges Natural Resources Management Board;
- Australian Water Association (AWA);
- Department for Transport, Energy and Infrastructure (DTEI);
- Department of Water, Land and Biodiversity Conservation (DWLBC);
- Environment Protection Authority (EPA);
- Housing Industry Association (HIA);
- Local Government Association (LGA);
- Department of Planning and Local Government (DPLG);
- South Australian Murray-Darling Basin Natural Resources Management Board;
- South Australian Water Corporation;
- Stormwater Industry Association (SIA); and
- Urban Development Institute of Australia (UDIA).

Technical Sub Committee

A technical sub committee, chaired by Dr David Kemp (DTEI), reviewed the technical and scientific aspects of the Technical Manual during development. This group included representatives from:

- Adelaide and Mt Lofty Ranges Natural Resources Management Board;
- City of Salisbury;
- Department for Transport, Energy and Infrastructure (DTEI);
- Department of Health;
- Department of Water, Land and Biodiversity Conservation;
- Department of Planning and Local Government; and
- Urban Development Institute of Australia.

From July 2010, DWLBC was disbanded and its responsibilities allocated to the newly created Department For Water (DFW) and the Department of Environment and Natural Resources (DENR).

Specialist consultant team

Dr Kylie Hyde (Australian Water Environments) was the project manager for a consultant team engaged for its specialist expertise and experience in water resources management, to prepare the Technical Manual.

This team comprised Australian Water Environments, the University of South Australia, Wayne Phillips and Associates and QED Pty Ltd.

Beecham and Associates prepared Chapter 16 of the Technical Manual.

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15.1 Overview

As detailed in **Chapter 1**, there are many different WSUD measures which together form a 'tool kit' from which individual measures can be selected as part of a specific design response suiting the characteristics of any development (or redevelopment).

This chapter of the Technical Manual for the Greater Adelaide Region is aimed at supporting those using models for design and assessment of developments containing WSUD measures.

The objectives of this chapter are to:

- Ensure a consistent, scientifically based approach is applied to the use of models; and
- Provide guidance on modelling tools available for use in the Greater Adelaide Region, without inhibiting innovative modelling approaches.

This chapter assumes that the reader has some knowledge of modelling tools, techniques and processes.

Description and Purpose

Models are playing an increasing role in urban water resource management. There are several reasons why models are being used in the field, including:

- Systems being studied are often highly complex and difficult to understand without tools such as models, e.g. large catchments with varying land uses and a convoluted drainage network that delivers runoff from land uses within the catchment at different times and rates of flow;
- There is rarely one single solution to an urban water management problem. Models provide a way to investigate and rank alternative approaches to water management; and
- Water distribution and drainage systems are highly non-linear and exhibit characteristics that are probabilistic or dependent on antecedent conditions in some cases. This requires modelling to enable an adequate understanding and assessment to be undertaken.

A 'model' can be defined as any organised procedure for the analysis of a problem. A model is a representation, often of a system. It attempts to replicate significant attributes of the prototype, but is simpler and is easier to build, change or operate.

There are many existing computer models which are powerful tools that can be utilised to design and estimate the performance of various WSUD measures. This means that the performance of different development proposals can be assessed and compared using a common measurement system.

Essentially, models allow the extrapolation from existing systems and knowledge to analyse potential situations. They are only useful to the extent that they accurately model the real world. Unrealistic models, however internally consistent or persuasive they may be, are misleading and risky (O'Loughlin 2007).

Scale and Application

Models can be employed to meet many different objectives during the planning, design and operation of a water management system; different types of models can be more appropriate than others depending on the question at hand.

The modeller should always ensure that the appropriate model is being applied for the situation being assessed. For example:

- As soon as an area being modelled exceeds a few hectares, has more than one land use, or requires a treatment train of runoff quality management facilities, there will be a need to adopt a distributed model rather than a lumped conceptual or spreadsheet type model;
- The model should provide results that meet the objectives of the task at hand; and
- The time step should match the response of the system being simulated.

In all cases, primary responsibility for modelling rests with the modeller with respect to ensuring that models are used as they are intended and with appropriate input and parameters.

The level of modelling required to be undertaken will often be defined by council development assessment officers and will be based on factors including:

- The level of impact the development is likely to have on the receiving waterways/water bodies; and
- The scale of the development.

15.2 Modelling Philosophy

Overview

In order of importance, the accuracy of models depends on:

- The amount of data used to build and operate the model;
- The experience or skill of the analyst; and
- The quality of the model.

Models are ineffective without data and calibration. Model results are sometimes accepted without adequate scrutiny because they are generated through a computer. The axiom 'rubbish in – rubbish out' applies to all computer programs. Results must not be accepted uncritically, but should be checked for consistency and logic, and if possible, validated against additional data.

Various procedures for dealing with uncertainties in model development, input data and predictions are summarised by De Jongh (1988).

Models should always be considered to be provisional with the understanding that they can always be improved. At any particular time, the task is not to develop a perfect, once-and-for-all model, rather it is to develop an effective model with the available resources, expecting this to be revised and improved in the future (O'Loughlin 2007).

When is a Model Required?

For small developments and redevelopments there will be instances where detailed modelling is not required. In such cases, the consenting authority should have a clear understanding of the minimum WSUD measures required for such developments. One way to deal with such cases is to develop 'deemed to comply' requirements, which are often presented in a spreadsheet format. Parramatta City Council in NSW has undertaken such an exercise in order to introduce WSUD requirements into its current on-site detention (OSD) policy.

A typical deemed to comply system may incorporate a combination of WSUD measures such as rainwater tanks, pervious pavements and rain gardens that have been pre-designed and pre-assessed by the consenting authority. In such cases it is important that adequate treatment trains, including pre-filtering, and storage components are incorporated into the deemed to comply systems.

Another way for small developments to size WSUD measures without the development of a model is the utilisation of type curves.

Models would generally be required on larger scale developments and/or where there is likely to be an impact as a result of the development.

Modelling Procedure

O'Loughlin (2007) recommends the following approach relating to analysis of a drainage system:

- Preliminary consideration of objectives;
- Data collection and site inspections;
- Building a conceptual model of the existing system;
- Model refinement, checking and calibration;
- Detailed runs;
- Identification of problems;
- Scoping (identification and initial assessment) of remedies; and
- Preparation of a report.

Model Conceptualisation

Models cannot in detail describe the physical flow processes in a catchment because of:

- Scale; and
- Insufficient data.

To simplify the model, a conceptual model should be developed before the detailed numerical model is developed. This conceptual model includes:

- Identification of the major flow processes; and
- Assumptions to reduce the complexity.

It ensures that the overall response of the hydrological model corresponds to that of the actual physical system.

Model Calibration

The purpose of calibration is to obtain a model which simulates in accordance with field data, such as flow rates from river gauging stations. To determine what constitutes satisfactory calibration, targets or criteria are usually set.

The number of parameters and possible combinations is often large and restrictions on sets of parameters may be applied to obtain a successful calibration including:

- Reducing the number of locations of measured field data (keeping the most reliable data);
- Restricting parameter intervals by setting minimum and maximum values; and
- Identifying parameters of high uncertainty.

Model Verification

The purpose of model verification is to test whether the calibrated model simulates in accordance with field data. To verify a model the user undertakes further simulations using field data that preferably has not been used in the model calibration stage. The model parameters should not be adjusted during the verification exercise. An acceptable criterion for model fit needs to be established and a statistical comparison is then made between the model verification results and the collected field data.

Sensitivity Analysis

All models involve a number of input factors that have different degrees of uncertainty. These will influence the outcomes of the study to varying extents.

The inputs are usually selected as 'most likely' values. The relative response of outputs to changes in inputs is termed their sensitivity. If large changes in an input produce much smaller changes in an output, the output is insensitive to that input.

A basic test of sensitivity is whether a percentage change in an input factor produces a higher or lower percentage change in an output.

Sensitivity analysis is a powerful yet simple technique for determining the effects of individual factors and their variations on the overall results of an analysis. It can be applied to any analysis that can be visualised as a system of inputs and outputs, and merely involves the repetition of calculations.

There is no formal procedure for sensitivity analysis. It can be applied in a number of ways, for example:

- By examining factors one at a time, and determining the variation in outcomes due to changes to a single factor, keeping the others at their 'most likely' values;
- By taking the 'best' or 'worst' estimates of all factors, to see how a system performs under extreme conditions; and
- By varying a factor sufficiently to cause a reversal of the outcome given its most likely value.

It is useful to carry out sensitivity analyses at a preliminary stage of a large study, to identify which factors have the greatest bearing on results. Particular attention can then be given to data collection and estimation of these, so that they can be estimated as accurately as possible. The less important factors need only be estimated approximately.

15.3 Data Sources

A range of data sources and information is required to be able to run various models.

Information regarding a number of typical data sources or modelling WSUD measures is provided below, including:

- Meteorological data;
- Flow data;
- Fraction impervious;
- Annual volumetric runoff coefficients; and
- Baseline water quality data.

Meteorological Data

Accurate and locally specific meteorological data is essential for reliable water quantity and quality modelling. Within some areas there are significant local spatial variations in rainfall and evaporation that, if overlooked, can significantly affect the reliability of modelling results. For local scale applications (say less than 100 square kilometres) it is typically acceptable to use data from one locally specific meteorological station. However, for more widespread or regional studies, it is important to ensure that adequate spatial meteorological data coverage of the study area is provided.

Local evapotranspiration data is preferred where available. In most cases, local data will not be available in which case average monthly data can be derived from the Climatic Atlas of Australia – Evapotranspiration.

Rainfall and evaporation data is available from the Bureau of Meteorology (www.bom.gov.au). The rainfall distribution map can be used to determine the appropriate weather station.

Flow Data

Ideally models should be calibrated against local flow data, however in most cases information is not available to achieve this.

Surface water data can be obtained from the Surface Water Archive which is maintained by the Department for Water.

Fraction Impervious

A number of models used to assess WSUD measures require the fraction impervious to be defined for the various land use types within the catchment.

Methods to determine the fraction impervious include:

- GIS data;
- Aerial photography; and
- Published local and national literature.

The following provides guidance on the fraction impervious information on the most typical source nodes in the Greater Adelaide Region:

- Residential = less than 50%;
- Commercial = approximately 70%;
- Industrial = approximately 85%; and
- Recreation = approximately 15%.

These figures are total fraction impervious, but actual runoff is related to the effective impervious area, which will depend on the percentage of the impervious area connected to the stormwater system (external to the site). The degree of connectivity with impervious and pervious areas can increase with high rainfall depth and intensity. This effective impervious area should be determined based on on-site stormwater management measures implemented.

Annual Volumetric Runoff Coefficients

For situations where no local data is available to calibrate the model, the selection and calibration of model input parameters should be based on replicating 'accepted' annual volumetric runoff coefficients (AVRC) – the ratio between the annual volume of runoff from a given catchment to the annual volume of rainfall that fell on that catchment, where appropriate, using the following equation:

$$\text{Annual Runoff Volume (ML)} = \frac{\text{Area } (m^2) \times \text{Avg Rainfall (m)} \times \text{AVRC}}{1000}$$

For example, if we assume that urban catchments have an AVRC of 0.4, a 1 hectare urban catchment with 500 mm average rainfall should be producing approximately (10,000m^2 x 0.5m x 0.4/1000) = 2 megalitres of runoff annually. The rainfall runoff model parameters should be selected and calibrated to approach this value where local data is unavailable.

Volumetric runoff coefficients are directly related to the effective impervious area, not the total impervious area. The volumetric runoff coefficient will depend on the form of development and on-site measures implemented.

It should be noted that in the Adelaide metropolitan area there is no significant contribution to runoff from pervious areas.

Baseline Water Quality Data

Stormwater Contamination

It is common for the processes of build up and washoff to be identified as being the main factors influencing the contamination of urban stormwater runoff. During dry weather, pollutants will accumulate in the catchment. These pollutants will build up on roads, pavements and any surface where pollutants can be transported. The amount of pollutant build up on a catchment depends on many factors. These include (Chiew et al. 1997):

- The rate of deposition of pollutants;
- The length of the antecedent dry period; and
- Any removal of pollutants by redistribution, decomposition, street sweeping or washoff.

Washoff is the removal of accumulated pollutants in a catchment area by rainfall and runoff. Falling raindrops and water runoff create turbulence during a storm event. This turbulence loosens particles and as a result suspends them in water and they are then carried into the drainage system. These particles may be dissolved pollutants or they may be sediments that are carrying pollutants. Pollutants that are washed out of the atmosphere by rainfall can add to the total load carried in the flow (Chiew et al. 1997).

Washoff is affected by factors such as:

- The overland velocity of runoff;
- Flow depth;
- Surface slope;
- Raindrop diameter;
- Rainfall intensity;
- Hydrologic roughness; and
- The amount of pollutants on the catchment surface.

The 'first flush' describes the washing action of the stormwater as it travels over the catchment during the early parts of the storm event. It is believed that the concentration of the pollutants in the runoff will be greatest in the early parts of the storm event. As the event continues, the level of contaminants in the runoff will reduce. The stormwater runoff from the later part of the storm event may dilute the contaminants that are present in the receiving water body.

Average Pollutant Levels

When no measured data is available for a WSUD study, it is important for modellers to be able to use average pollutant concentrations for given land uses. An initial study undertaken by Duncan (1999) was based on data obtained from various field investigations spanning back to before 1965. It was the intention of Duncan to investigate stormwater runoff quality in relation to land use and catchment characteristics. The findings of Duncan were modified and updated and then presented in Duncan (2005).

The figures that are contained in **Appendix A** are adapted from Duncan (2005). The mean pollutant concentration of the stormwater in Duncan's (2005) investigation for various land uses is represented by the centre line of the bar graphs. Plus and minus one standard deviation is represented by the grey bars.

15.4 Modelling Tools

There are numerous packages and approaches that can be applied to simulate water management systems.

A number of available modelling tools are described briefly below. They have been selected due to their availability and wide use through the industry, their applicability to WSUD and South Australian conditions.

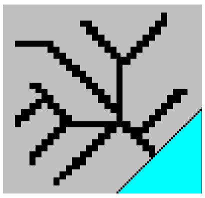
A summary of the modelling tools available and the WSUD measures that they model is included in **Table 15.1**.

It is important to note that the information provided below on any modelling system neither endorses any of these modelling systems, nor assures the quality of results that will be obtained from their use.

Table 15.1 Summary of Model Applications (at July 2009)

WSUD Element	MUSIC	EPA SWMM	XP-SWMM	Water Cress	Drains	Hec-Ras	SWITCH	Switch2	PermPave	Raintank Analyser	E2
On-site detention	Y	Y	Y	Y	Y	N	N	Y	Y	N	N
On-site retention	Y	Y	Y	Y	N	N	Y	Y	Y	N	N
Rainwater tanks	Y	Y	Y	Y	N	N	N	Y	N	Y	Y
Pervious pavements	Y	N	N	N	N	N	Y	Y	Y	N	N
Buffer strips	Y	N	N	N	N	Y	N	N	N	N	Y
Swales	Y	Y	Y	N	N	Y	N	N	N	N	Y
Bioretention systems	Y	Y	Y	N	Y	Y	N	Y	N	N	Y
Sedimentation basins	Y	Y	Y	N	Y	Y	N	N	N	N	Y
Ponds	Y	Y	Y	N	N	Y	N	N	N	N	Y
Constructed wetlands	Y	Y	Y	Y	Y	Y	N	N	N	N	Y
Infiltration systems	Y	Y	Y	Y	N	Y	Y	Y	Y	N	N
Gross pollutant traps	Y	N	N	N	N	N	N	N	N	N	Y
Oil and grit separators	N	N	N	N	N	N	N	N	N	N	N
Stormwater harvesting	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y
Rain gardens	Y	N	Y	Y	N	N	N	Y	N	N	N
Green roofs	N	N	Y	N	N	N	N	N	N	N	N
Street sweeping	N	N	Y	N	N	N	N	N	N	N	N
On-site wastewater management	N	N	N	N	N	N	N	N	N	N	N
Community wastewater management schemes	N	N	N	N	N	N	N	N	N	N	N
Demand reduction	N	N	N	Y	N	N	N	Y	N	N	Y

DRAINS



DRAINS is a multi-purpose Windows program for designing and analysing urban stormwater drainage systems and catchments.

The program can be used to analyse peak flows, volumes and system deficiencies.

DRAINS simulates the conversion of rainfall patterns to stormwater runoff hydrographs and routes these through networks of pipes, channels and streams, integrating:

- Design and analysis tasks;
- Hydrology (four alternative models) and hydraulics (two alternative procedures);
- Closed conduit and open channel systems;
- Headwalls, culverts and other structures;
- Stormwater detention systems; and
- Large scale urban and rural catchments.

DRAINS can carry out hydrological modelling using ILSAX, rational method and storage routing models, together with quasi-unsteady and unsteady hydraulic modelling of systems of pipes, open channels and surface overflow routes. It includes two automatic design procedures for piped drainage systems, connections to CAD and GIS programs, and an in-built Help system.

The runoff routing modelling facilities in DRAINS can be configured to emulate the RORB, RAFTS and WBNM modelling structures.

E2

E2 is a software product for whole-of-catchment modelling. It is designed to allow modellers and researchers to construct models by selecting and linking component models from a range of available choices. E2 enables a flexible modelling approach, allowing the attributes and detail of the model to vary in accordance with modelling objectives.

In E2, the model structure and algorithms are not fixed. They are defined by the user, who can choose from a suite of available options. Model selection requires the user to be familiar with the detail, applicability and data requirements of component models, and the implications of joining component models. E2 is therefore intended to be a tool for experienced catchment modellers.

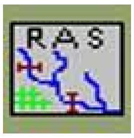
Environment Protection Agency StormWater Management Model (EPA SWMM)

The US Environment Protection Agency (EPA) Storm Water Management Model (SWMM) is a dynamic rainfall runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. SWMM 5 is a complete rewrite of the first version developed in 1971 and offers GIS based input formats and extensive graphical outputs, including colour coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses. While free, there is no support from the EPA, only a SWMM Users Forum.

SWMM accounts for various hydrologic processes that produce runoff from urban areas. These include:

- Time varying rainfall;
- Evaporation of standing surface water;
- Rainfall interception from depression storage;
- Infiltration of rainfall into unsaturated soil layers;
- Percolation of infiltrated water into groundwater layers;
- Interflow between groundwater and the drainage system; and
- Non-linear reservoir routing of overland flow.

Hydraulic Engineering Centre River Analysis System (HecRas)



HecRas performs one dimensional hydraulic calculations for a full network of natural and constructed channels for steady and unsteady flow scenarios, sediment transfer/mobile bed computations and water temperature modelling.

Model for Urban Stormwater Improvement Conceptualisation (MUSIC)

MUSIC is designed to simulate urban runoff systems operating at a range of temporal and spatial scales and provides a user friendly interface to allow complex stormwater management scenarios to be quickly and efficiently created, with results viewed using a range of graphical and tabular formats. MUSIC provides the ability to simulate both quantity and quality of runoff from catchments and the effect of treatment facilities on these components.

MUSIC - Model for Urban Stormwater Improvement Conceptualisation

MUSIC is an aid to decision making. It enables users to evaluate conceptual designs of stormwater management systems to ensure they are appropriate for their catchments. By simulating the performance of stormwater quality improvement measures, MUSIC determines if proposed systems can meet specified water quality objectives.

MUSIC will simulate the performance of a group of stormwater management measures, configured in series or in parallel to form a treatment train. MUSIC runs on an event or continuous basis, allowing rigorous analysis of the merit of proposed strategies over the short-term and long-term.

Specifically, the software enables users to:

- Determine the likely water quality emanating from urban catchments;
- Predict the likely performance of specific structural best management practices (BMPs) in protecting receiving water quality;
- Design an integrated stormwater management scheme; and
- Evaluate the success of structural BMPs, or a stormwater management scheme, against a range of water quality standards.

PermPave

PermPave analyses and designs pervious pavement systems for stormwater runoff quantity (flood), quality and harvesting:

- Flood mitigation – using the design rainfall approach according to Australian Rainfall and Runoff. Outputs include inflow and outflow hydrographs, required storage capacity of pavement and depth;
- Water quality improvement – a simple water quality improvement analysis is based on hydrological effectiveness, derived from continuous time series modelling using 6 minute historical rainfall data; and
- Water harvesting – yields-storage relationship and suggested storage, based on unit storage volume benefit and disbenefit approach.

The program is able to design a system for each of the capital cities.

Rainfall Runoff Library

The Rainfall Runoff Library is designed to simulate catchment runoff and is typically used to fill gaps in data and extend streamflow records.

The Rainfall Runoff Library includes the following models:

- AWBM

  The AWBM is a catchment water balance model that can relate runoff to rainfall with daily or hourly data, and calculates losses from rainfall for flood hydrograph modelling.

- Sacramento

  The Sacramento model is a continuous rainfall runoff model used to generate daily streamflow from rainfall and evaporation records.

- SimHyd

  SimHyd is a daily conceptual rainfall runoff model that estimates daily stream flow from daily rainfall and areal potential evapotranspiration data.

- SMAR

  The soil moisture and accounting model (SMAR) is a lumped conceptual rainfall runoff water balance model with soil moisture as a central theme. The model provides daily estimates of surface runoff, groundwater discharge, evapotranspiration and leakage from the soil profile for the catchment as a whole. The surface runoff component comprises overland flow, saturation excess runoff and saturated throughflow from perched groundwater conditions with a quick response time.

- Tank

  The tank model is a very simple model, composed of four tanks laid vertically in series. Precipitation is put into the top tank, and evaporation is subtracted sequentially from the top tank downwards. As each tank is emptied the evaporation shortfall is taken from the next tank down until all tanks are empty.

  The tank model is applied to analyse daily discharge from daily precipitation and evaporation inputs.

Raintank Analyser

The Raintank Analyser program can be utilised to assess the following various aspects of rainfall harvesting:

- Yields;
- Cost analysis; and
- Tank size selection.

This software is primarily intended for sizing raintanks for domestic use of water inhouse as well as outdoors, if required. However, there is a 20,000 litre limit to storage volumes in the model.

The model can also be applied to commercial/industrial situations provided the 20,000 litre limit is recognised. In these situations where very large catchment (roof) areas are available, then a solution to the problem of 'sizing' can be found by segmenting the catchment so that each segment requires a rainwater tank of capacity not exceeding 20,000 litres.

Stormwater Infiltration Techniques: Community Homepage (SWITCH)

SWITCH enables hydrologic analysis and sizing of infiltration systems to be undertaken.

This model was originally developed as a design tool to size stormwater infiltration systems. It has since been expanded to design other WSUD components such as:

- Rainwater tanks;
- Swales;
- Bioretention systems; and
- Sand filters.

SWITCH is a design storm based model.

The SWITCH design model uses the CIRIA method (Butler and Davies 2000) for the sizing of infiltration systems. This is a design storm approach that requires the determination of the worst or critical storm. To facilitate this, SWITCH includes a routine that can automatically run design storms from 1 to 100 years ARI and durations from five minutes to 72 hours for a number of locations across Australia. The program selects the critical storm and proceeds to size the infiltration system. It also estimates the time to empty the device following the occurrence of the critical duration design storm.

Switch2

Switch2 is a total water balance model that is able to take into account end user demands and compute water supply (conservation) and stormwater discharges at six minute time intervals using continuous simulation modelling. Switch2 has a spatial resolution ranging from 50 m^2 to 5 ha.

The SWITCH model was originally developed as a design tool to size stormwater infiltration systems. The Switch2 program has been expanded to enable design of other WSUD measures such as rainwater tanks, swales and bioretention systems.

The original SWITCH software is a design storm based model while Switch2 is a continuous simulation model (CSM) that uses observed or disaggregated rainfall down to one minute time intervals. The Switch2 model can process more than 100 years of rainfall data at one minute time intervals.

Both versions currently use deterministic loss modelling and water balance computational techniques, although it is planned that future versions of Switch2 will incorporate both deterministic and stochastic rainfall disaggregation capabilities. Water quality and life cycle costing modules are also currently under development.

The SWITCH and Switch2 models have recently been integrated into a common, Windows based graphical user interface, the opening splash screen for which is shown in **Figure 15.1**. A purpose designed browser application object provides connectivity between the two models and an Education and Design Guideline package. From this website users can look up design data such as soil infiltration rates or geofabric specifications.

The design guidelines, which are presented through a web based system, include topics such as feasibility, site evaluation, detailed design methodologies, construction and installation, operation and maintenance requirements, and performance review.

For Switch2, the data entry also includes an end user model to estimate both inside and outside water consumption.

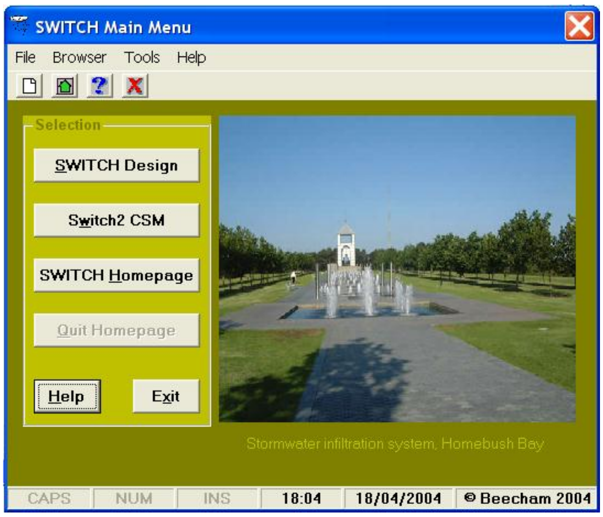


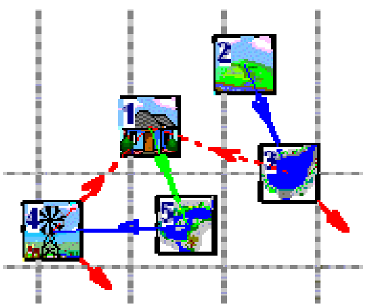
Figure 15.1 Opening SWITCH Screen

Once a daily consumption has been established, a graphically adjustable diurnal distribution is then applied.

The model outputs include system dimensioning, performance statistics, rainfall data and loss estimations at the selected time scales. Loss estimations are categorised as depression storage, evapotranspiration, vegetation interception and soil infiltration. In addition, the Switch2 model is able to calculate both rainwater tank overflow volumes and the replenishing of supplies using municipal drinking (potable) water during extended dry periods. Topping up of the system can be specified to occur when the storage volume falls below a nominal volume (for example, 20% of the tank capacity for systems collecting surface water for irrigation and 30% of the tank capacity for systems harvesting rainwater for toilet flushing).

Supplementation using municipal drinking water can be converted to a water supply cost. The program can therefore provide an estimate of the potential cost savings associated with various types of WSUD systems.

WATER-Community Resource Evaluation and Simulation System (WaterCress)



WaterCress is a PC based water balance model for designing and testing trial layouts of water systems using multiple sources of water. WaterCress is designed to meet the problems of exploring alternative systems layout at the feasibility stage. The model uses a trial and error approach to determine the feasibility of water resource projects.

WaterCress is particularly useful in evaluating and designing water systems for:

- Subdivisions where alternatives to connection to existing water supply mains and sewers may be costly and/or opportunities are sought to utilise drainage water for amenity enhancement or supply;
- Isolated communities in drier areas where water use efficiency is particularly important; and/or
- Design situations where environmental impacts must be minimised.

WaterCress allows you to simulate real life water system layout as an assembly of nodes joined by drainage links. The nodes represent all conventional water supplies such as catchments, dams, groundwater bores, inhouse demands, irrigation areas and pumps, but also include non-conventional supply sources and management processes involved in such processes as the recycling of treated wastewater at local and regional scales, and capture, treatment and storage of urban stormwater in rainwater tanks, wetlands and aquifers.

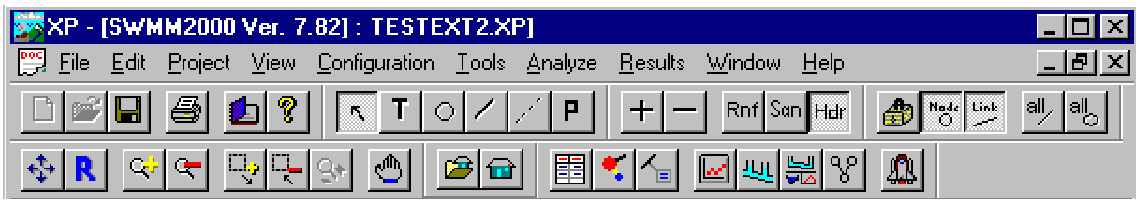
WaterCress's wastewater treatment system representation is qualitative rather than quantitative. WaterCress's separation of wastewater streams occurs in the town node.

The strengths of WaterCress lie in its storage and water reuse modelling, with its development originating from the requirement to more accurately model farm dams within rural catchments and the need to incorporate custom water reuse layouts to lot or subdivision scale models.

XP StormWater Management Model (XP-SWMM)

XP-SWMM is a friendly, graphics based stormwater and wastewater decision support system. It is a link node model that performs hydrology, hydraulics and quality analysis of stormwater and wastewater drainage systems including wastewater treatment plants, water quality control devices and best management practices (BMPs).

Links represent hydraulic elements for flow and constituent transport through the system (for example: pipe, channel, pump, weir, orifice regulator, real time control device, etc). There are more than 30 different types of conduits available in XP-SWMM.



XP-SWMM can be used in a wide variety of water quality studies. Processes that can optionally be simulated within the software include pollutant build up, washoff during rainfall, transport, advection, sedimentation and biochemical processes. In all cases the user will need to choose suitable values for the process parameters.

XP-SWMM and its predecessor US EPA SWMM were created to provide a tool capable of modelling the total water cycle from stormwater and wastewater flow, and pollutant generation to simulation of the hydraulics in any combined system of open and/or closed conduits with any boundary conditions.

Some of the many applications for which XP-SWMM is well suited include:

- Urban stormwater hydrology;
- Rural stormwater hydrology;
- Subdivision drainage;
- Major and minor drainage system hydraulics;
- Hydraulics of open channels and watercourses;
- Stormwater quality modelling;
- Wastewater Dry Weather Flow and Wet Weather Flow generation;
- Pollutant routing;
- Analysis of best management practices for treatment of stormwater runoff; and
- Treatment analysis.

15.5 Case Studies

Modelling Potential Phosphorus Reduction in the River Torrens by Assessment of Various WSUD Strategies

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) was developed by the CRC for Catchment Hydrology as a tool for simulating urban stormwater systems for a range of catchment scales and application.

MUSIC is particularly useful as conceptual design tool which allows for water quality improvement assessment in relative terms.

This model was applied in a case study conducted for the Torrens Taskforce Committee, assessing the capacity of several WSUD treatment options and strategies for reducing nutrient load into the River Torrens within the City of Adelaide. The assessment was carried out on the Hectorville subcatchment, which is one of several typical urban subcatchments draining into the River Torrens.

Figure 15.2 MUSIC Model Subcatchments Representation

Source: University of South Australia

The 62 hectare Hectorville subcatchment was modelled by dividing the area into 12 areas of approximately 5 hectare, each having 23% of roadway coverage and the remaining as residential land. The model subcatchments are illustrated in **Figure 15.2**.

The imperviousness and connectivity of the residential area and other catchment specific characteristics were determined from multiple sources including:

- GIS data;
- Aerial photography; and
- Published local and national literature.

Water quality improvements of the modelled technologies were based on the default trends available in MUSIC, using a six minute time step.

Potential WSUD strategies which could assist the ultimate objective of runoff nutrient reduction were assessed. The effectiveness of the strategies was assessed from allotment to catchment scale:

- Allotment scale – source control such as rainwater tanks, rain gardens and soakways treating 25%, 50% and 75% of the catchment;
- Street scale – swales, bioretention systems and pervious pavements treating 25%, 50% and 75% of the catchment; and
- Catchment scale – infiltration basin (1000 m^2) and Wetland (1000 m^2).

In addition, assessment was also conducted by applying the treatment train approach, combining several WSUD strategies at different scales. The effects of an increase in urban density were also considered.

Assessment was also undertaken of the potential benefits associated with:

- Harvesting and reuse;
- Flood mitigation;
- Economics; and
- Social acceptance and values.

This was conducted as part of a multi-criteria decision analysis aimed at identifying the most appropriate strategies for addressing the wide scope of objectives in the changing urban environment. Economic assessment was conducted using the life cycle cost analysis feature in MUSIC.

Overall, the model provided comparable quality data which is suitable for initial stormwater management strategy assessment. The model could potentially be utilised for more detailed planning but would require accurate, catchment specific data and monitoring.

Modelling Stormwater Runoff Quantity and Quality in the Parafield Catchment

In 2004, the Urban Water Resources Centre at the University of South Australia conducted a study into the feasibility of modelling stormwater runoff and quality in the Parafield Drain in the City of Salisbury. The main feature explored in this study was the ability of build up and washoff models to accurately predict the concentration of heavy metals in the runoff.

SWMM is a comprehensive modelling tool, commonly used for stormwater, sanitary and river systems. XP-SWMM, a commercially available extended version of the model originally developed by the US EPA, was utilised to perform the analysis.

The XP-SWMM program consists of several modules, each designed to represent specific processes in the catchment. The modules implemented in this project were:

- The rainfall runoff module;
- The hydraulic module; and
- The water quality module.

The Parafield Drain model was developed in several stages, addressing the issues of catchment characteristics, hydraulic system representation and pollutant build up and washoff processes. Although the program allows for a very accurate physical representation of the system modelled, in this particular application a more conceptual approach was adopted as described below:

- Catchment – the 1600 hectares catchment was represented in the model by three subareas. The first subarea accounted for the 400 hectares of rural land in the catchment, while the small commercial area was incorporated into the surrounding residential area and divided into an additional two subareas. Catchment characteristics such as depression storage, infiltration rates and overland flow were based on recommended typical values.
- Hydraulic system – the drainage system was simplified to only assess the main channel leading to the harvesting location.
- Pollutant functions – the suitability of several functions and parameters was considered in order to determine the most suitable representation of heavy metals in the runoff. The selected approach was based on a combination of a typical build-up/washoff model combined with an assumed concentration in precipitation. Although this is not the correct physical representation, it resulted in quite accurate predication of the total mass of pollutants.

Both runoff and pollutant loads were analysed using local 6 minute rainfall data and calibrated using historical monitoring data. The model was then validated using six months of rainfall runoff and quality data, and provided a good prediction of cumulative pollutant accumulation in the receiving system.

Modelling Supply, Demand and Operation for the Non-potable Water System in Mawson Lakes

Mawson Lakes is a world class sustainable development, incorporating dual reticulated water systems for drinking and non-drinking supply.

Drinking water is used for the following indoor uses:

- Drinking;
- Kitchen;

- Laundry; and
- Bathroom.

The non-drinking water is used for:

- Toilet flushing;
- Garden;
- Park irrigation; and
- Top up of the constructed lakes.

The non-drinking water supply is based on treated wastewater and supplemented by captured stormwater runoff, both from immediate or adjacent sources. This combined, innovative approach resulted in a unique scheme.

A WaterCress model of the Mawson Lakes development in the City of Salisbury was constructed in 2002 in order to simulate the operation of the local non-drinking water system.

WaterCress is a locally developed, total water balance model widely used in a range of projects in South Australia. The model is suitable for a variety of planning and water resource management applications.

The model utilised many of the unique features of the program and was used to estimate:

- Stormwater and wastewater production and storages;
- Non-drinking water supply and demand;
- The salinity of the water; and
- The reliability of supply in terms of volume and quality.

The WaterCress model assessed the performance of the system based on a 100 year historical rainfall record and was used to estimate the ability of the system to sustainably meet demands. The node layout of the WaterCress model is illustrated in **Figure 15.3**.

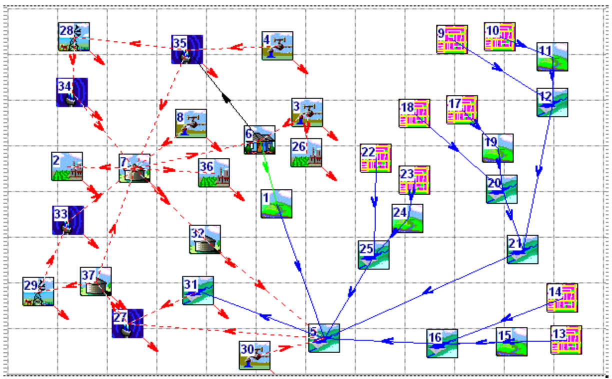


Figure 15.3 Mawson Lakes WaterCress Node Layout

The model considered the following matters:

- Non-drinking water demand – combination of constant toilet flushing demand, seasonal public and private irrigation demand and lake evaporation replacements. Rainfall and evaporation relations and their implications were also considered and resulted in a realistic, variable annual demand.
- Stormwater runoff and capture – modelled assuming both partial and full development conditions. Intercatchment connection was also considered to augment supplies in dry years.
- Wastewater reclamation – modelled based on inhouse use and incorporated losses and increased salinity. Constant groundwater infiltration was also considered and affected both volumes and water quality (salinity).
- Reliability of supply – determined by the ability of the system to meet annual demands under the specific rainfall, evaporation and volumes held in storage. Maximum and average shortfalls were determined based on historical records and provided an estimate of the development's reliance on mains water.
- Quality of supply – quality deterioration of recycled water and wetland salinity issues were considered and control methods were suggested.

Modelling the Mawson Lakes non-drinking water system resulted in estimates of system efficiency and better understanding of the long-term management challenges of this unique system. The model was also useful for determining a pre-commissioning strategy for drought proofing the aquifer storage systems against salinisation processes.

Estimating Catchment Yield for the Parafield Aquifer Storage and Recovery Scheme

The Parafield Drain Scheme in the City of Salisbury is a world class system designed for harvesting urban stormwater for industrial and domestic reuse applications.

Runoff from the Parafield and Ayfield catchments is diverted into a series of instream storage and treatment basins.

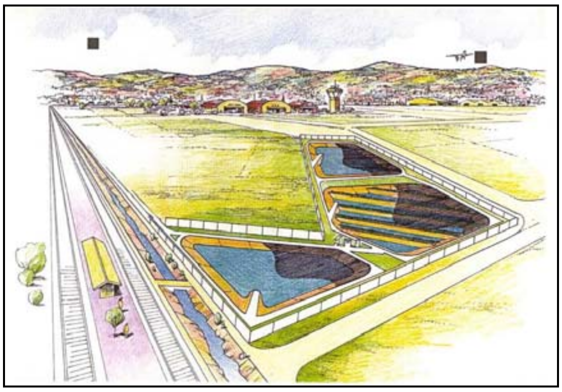


Figure 15.4 Conceptual Layout of the Parafield Drain Scheme

Treated water is directly reused by local industry and the Mawson Lakes development while excess water is stored in a tertiary aquifer.

The storage of water in the underlying aquifer enables continuous water supply during dry periods. The capture, treatment and reuse of urban stormwater, previously free flowing into Gulf St Vincent, also significantly reduces the environmental footprint of urban catchments on the aquatic system.

A WaterCress model of the Parafield Drain and managed aquifer recharge (MAR) scheme was constructed by Richard Clark and Associates in 2001, in order to estimate the harvesting yields and performance of the system. WaterCress is a locally developed, complete water balance model which is widely used for numerous applications in South Australia.

The WaterCress model was used to:

- Estimate runoff yield and salinity;
- Determine the initial aquifer buffer storage requirements; and
- Conclude on the expected water supply from the system.

Modelling was conducted based on historical, 95 year daily rainfall records and calibrated with an estimated long-term average annual runoff. The model consisted of three components representing the catchment, the capture and treatment system, and the aquifer injection and recovery storage zone.

Land use within the Ayfield and Parafield catchments was assessed and divided into five individual classifications, based on typical runoff coefficients. The average runoff from historical data and average annual rainfall was determined and verified by available records of similar, nearby catchments. The model was also used to determine the expected salinity levels based on a typical log linear relationship with runoff volumes.

Modelling of the operation of the instream storage and treatment system was also conducted in order to analyse the actual harvesting capacity of the system. The limiting factors adopted were based on:

- The basins storage levels;
- The capacity of the pumps; and
- Maximum allowable supply salinity level lower than 1000 milligrams/litre.

The efficiency of the system was determined by comparing catchment yields with subsequent direct supply or aquifer storage.

The WaterCress model was also used to:

- Analyse the water losses due to mixing and migration within the storage aquifer;
- Determine the volume required to establish an initial buffer zone; and
- Estimate the time required to inject this volume.

Modelling the Parafield system revealed the average system supply efficiency based on historical records and the sensitivity of this estimate to variations in recharge rate and accepted supply salinity levels. This information significantly assisted in understanding the potential response of the system to annual variation in rainfall, runoff and stormwater quality.

15.6 Useful Resources and Further Information

General

www.stormwater.asn.au/sa/

Stormwater Industry Association South Australia

www.urbanwater.info/engineering/modelling.cfm

Urban Water Information

Guidelines (Interstate)

http://waterbydesign.com.au/musicguide/

MUSIC Modelling Guidelines, South East Queensland

www.melbournewater.com.au/content/library/wsud/Guidelines_For_The_Use_Of_MUSIC.pdf

MUSIC Input Parameters, Melbourne Water

Models

www.ewatercrc.com.au

Hydrological modelling and research information

www.toolkit.net.au/tools/

Provides eWater Toolkit which is a range of online modelling tools, including MUSIC, available for specific purposes.

www.toolkit.net.au/cgi-bin/WebObjects/toolkit.woa/1/wa/products?wosid=rQ6FU5PiTotw09P5pHZk4w#

Catchment Modelling Toolkit

www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html

HecRas

www.cmaa.com.au/html/TechInfo/TechInfoPaving_permeable.html

PermPave

www.unisa.edu.au/water/UWRG/publication/raintankanalyser.asp

Raintank Analyser

www.watercom.com.au/index.html

Watercom

www.waterselect.com.au

WaterSelect

(Websites current at August 2010)

15.7 References

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Chiew, F. H. S., Mudgway, L. B., Duncan, H. P., McMahon, T. A. (1997). *Urban Stormwater Pollution*. Cooperative Research Centre for Catchment Hydrology.

De Jongh, P. (1988). *Uncertainty in Environmental Impact Assessment, Theory and Practice*. London.

Duncan, H. (1999). *Urban Stormwater Quality: A Statistical Overview.* Cooperative Research Centre for Catchment Hydrology. Melbourne.

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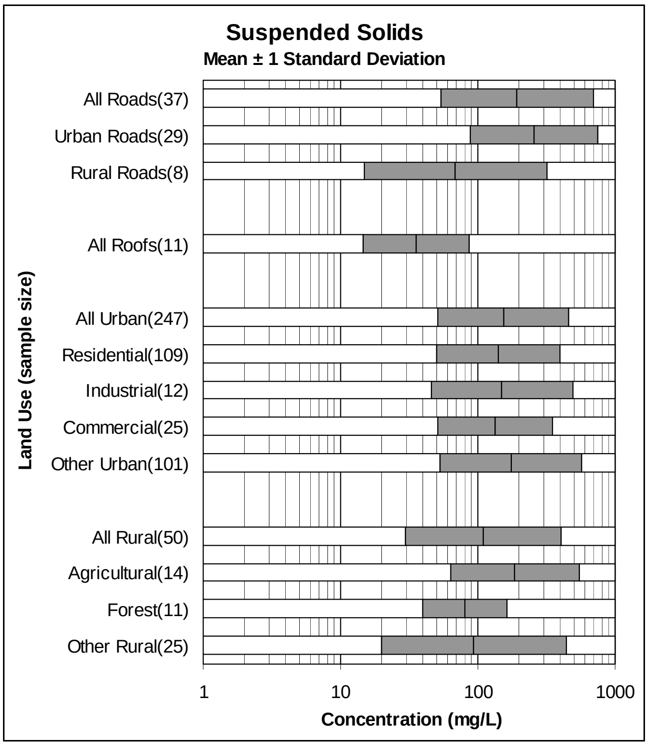
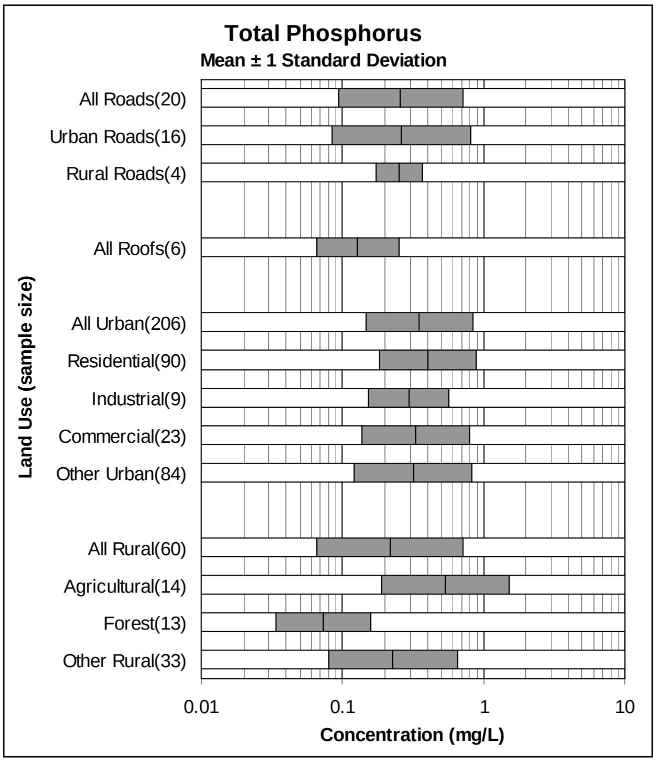
(Websites current at August 2010)

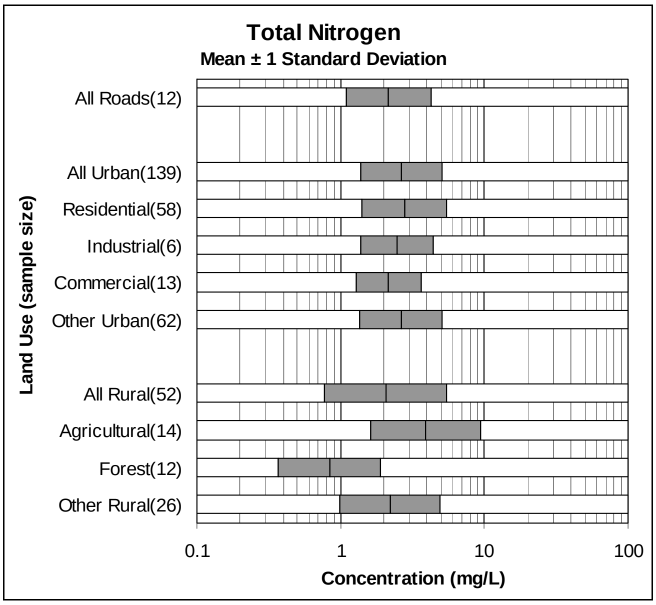
Appendix A
Baseline Water Quality Data

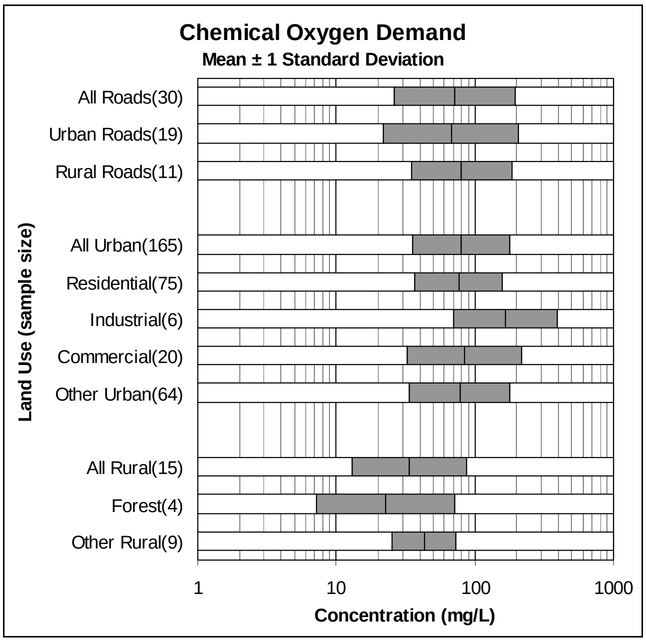
Baseline Water Quality Data

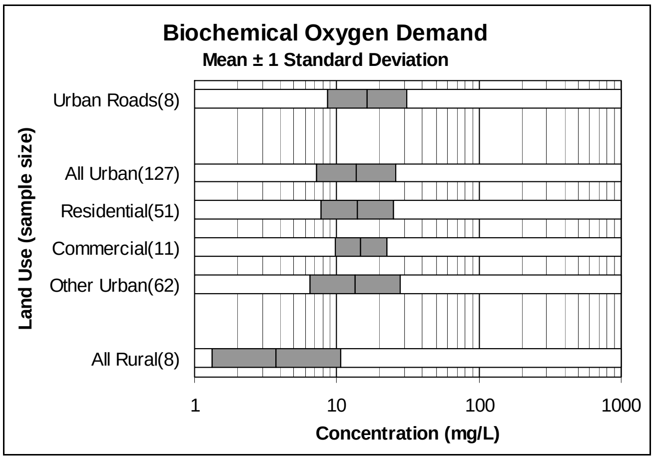
Adapted from Duncan (2005).

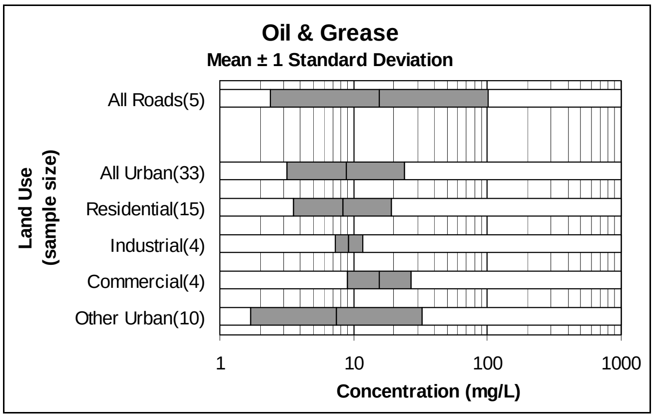


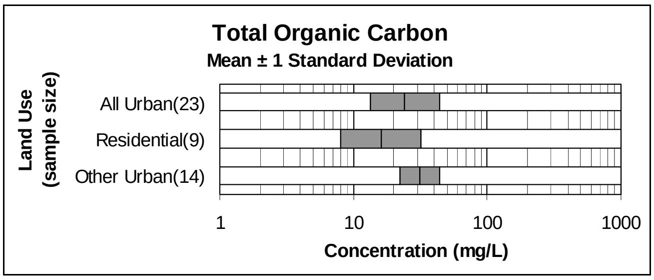

Total Phosphorus
Mean ± 1 Standard Deviation
All Roads(20)
Urban Roads(16)
Rural Roads(4)
All Roofs(6)
All Urban(206)
Residential(90)
Industrial(9)
Commercial(23)
Other Urban(84)
All Rural(60)
Agricultural(14)
Forest(13)
Other Rural(33)
Land Use (sample size)
0.01
0.1
1
10
Concentration (mg/L)


Total Nitrogen
Mean ± 1 Standard Deviation
All Roads(12)
All Urban(139)
Residential(58)
Industrial(6)
Commercial(13)
Other Urban(62)
All Rural(52)
Agricultural(14)
Forest(12)
Other Rural(26)
Land Use (sample size)
0.1
1
10
100
Concentration (mg/L)

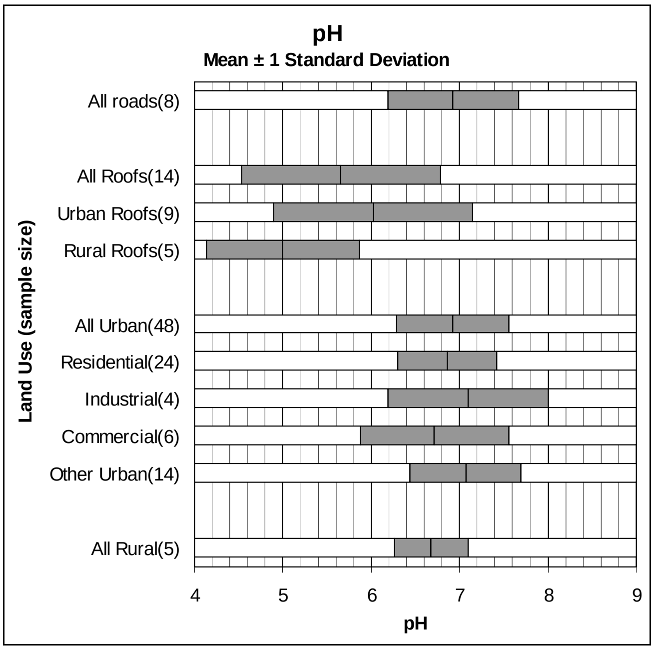

Chemical Oxygen Demand
Mean ± 1 Standard Deviation
All Roads(30)
Urban Roads(19)
Rural Roads(11)
All Urban(165)
Residential(75)
Industrial(6)
Commercial(20)
Other Urban(64)
All Rural(15)
Forest(4)
Other Rural(9)
Land Use (sample size)
1
10
100
1000
Concentration (mg/L)


Biochemical Oxygen Demand
Mean ± 1 Standard Deviation
Urban Roads(8)
All Urban(127)
Residential(51)
Commercial(11)
Other Urban(62)
All Rural(8)
Land Use (sample size)
1
10
100
1000
Concentration (mg/L)

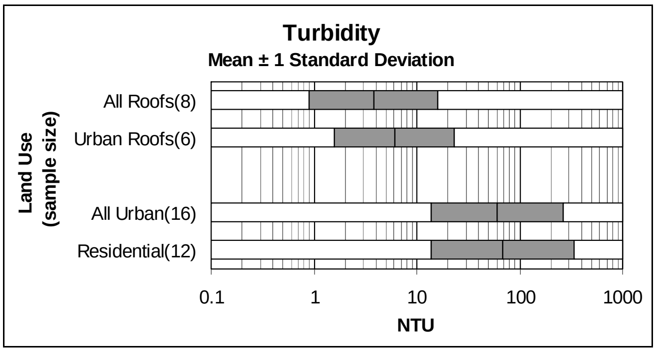

Oil & Grease
Mean ± 1 Standard Deviation
All Roads(5)
All Urban(33)
Residential(15)
Industrial(4)
Commercial(4)
Other Urban(10)
Land Use (sample size)
1
10
100
1000
Concentration (mg/L)



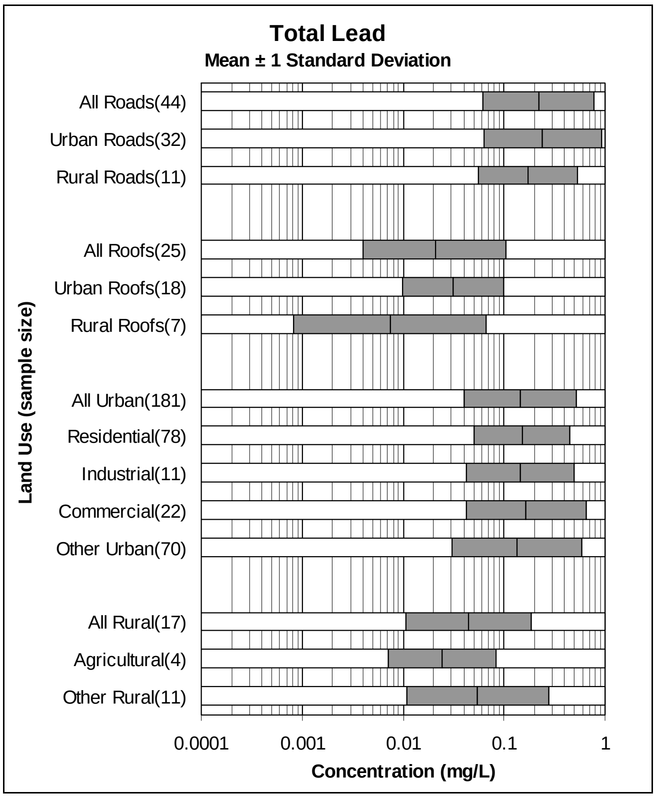
Total Organic Carbon
Mean ± 1 Standard Deviation
Land Use (sample size)
All Urban(23)
Residential(9)
Other Urban(14)
1
10
100
1000
Concentration (mg/L)

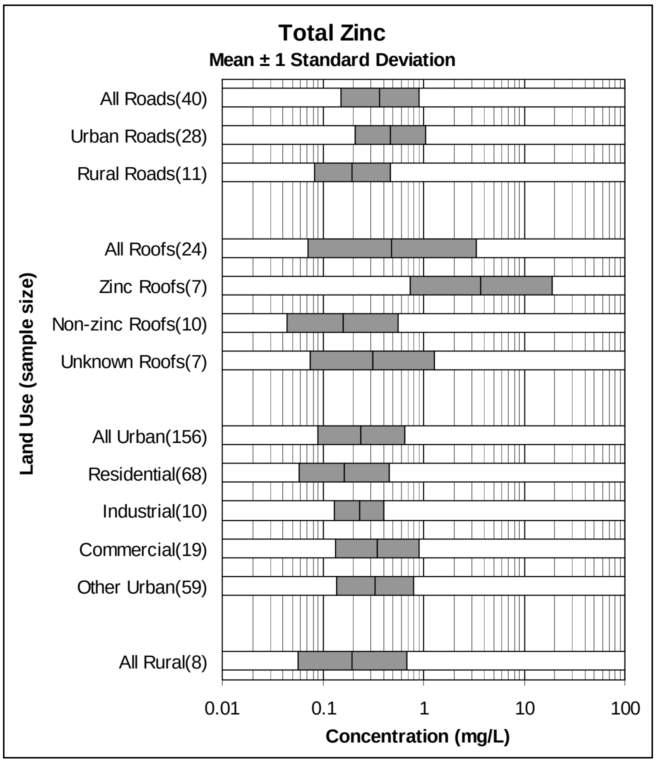


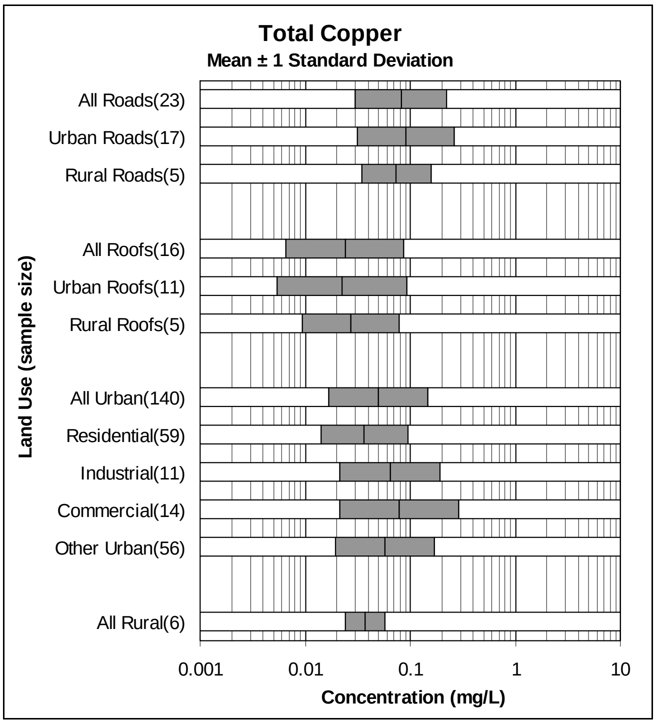
pH
Mean ± 1 Standard Deviation
Land Use (sample size)
All roads(8)
All Roofs(14)
Urban Roofs(9)
Rural Roofs(5)
All Urban(48)
Residential(24)
Industrial(4)
Commercial(6)
Other Urban(14)
All Rural(5)
4
5
6
7
8
9
pH

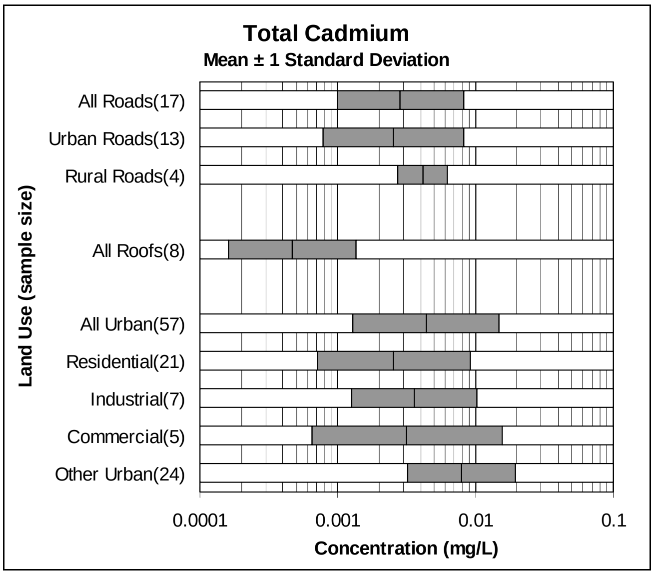


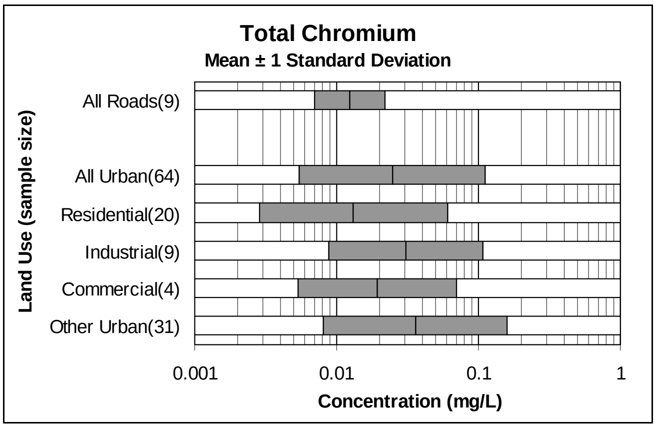
Turbidity
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roofs(8)
Urban Roofs(6)
All Urban(16)
Residential(12)
0.1
1
10
100
1000
NTU

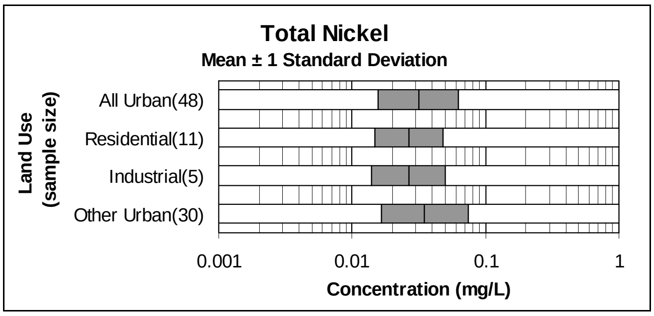

Total Lead
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roads(44)
Urban Roads(32)
Rural Roads(11)
All Roofs(25)
Urban Roofs(18)
Rural Roofs(7)
All Urban(181)
Residential(78)
Industrial(11)
Commercial(22)
Other Urban(70)
All Rural(17)
Agricultural(4)
Other Rural(11)
0.0001
0.001
0.01
0.1
1
Concentration (mg/L)

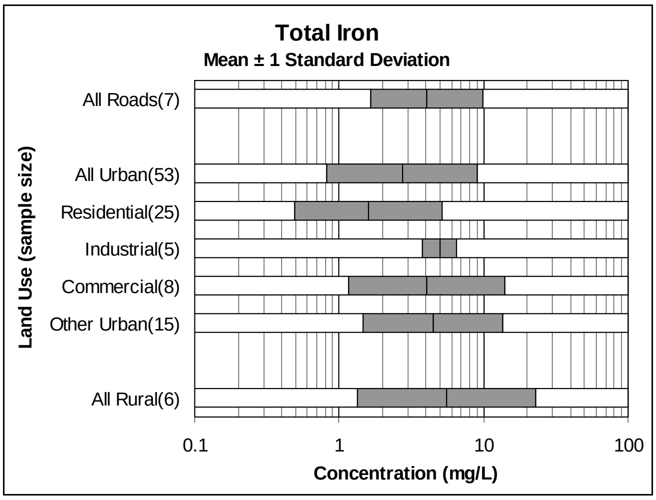

Total Zinc
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roads(40)
Urban Roads(28)
Rural Roads(11)
All Roofs(24)
Zinc Roofs(7)
Non-zinc Roofs(10)
Unknown Roofs(7)
All Urban(156)
Residential(68)
Industrial(10)
Commercial(19)
Other Urban(59)
All Rural(8)
0.01
0.1
1
10
100
Concentration (mg/L)

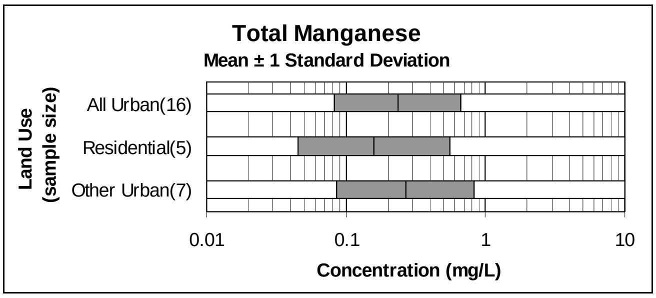

Total Copper
Mean ± 1 Standard Deviation
All Roads(23)
Urban Roads(17)
Rural Roads(5)
All Roofs(16)
Urban Roofs(11)
Rural Roofs(5)
All Urban(140)
Residential(59)
Industrial(11)
Commercial(14)
Other Urban(56)
All Rural(6)
Land Use (sample size)
0.001
0.01
0.1
1
10
Concentration (mg/L)

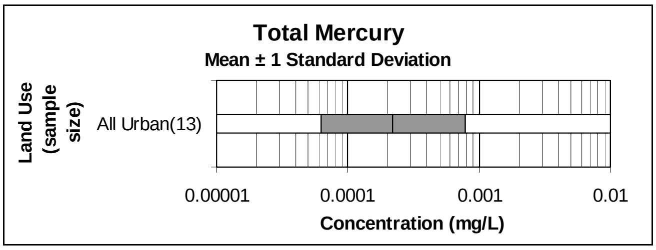

Total Cadmium
Mean ± 1 Standard Deviation
All Roads(17)
Urban Roads(13)
Rural Roads(4)
All Roofs(8)
All Urban(57)
Residential(21)
Industrial(7)
Commercial(5)
Other Urban(24)
Land Use (sample size)
0.0001
0.001
0.01
0.1
Concentration (mg/L)

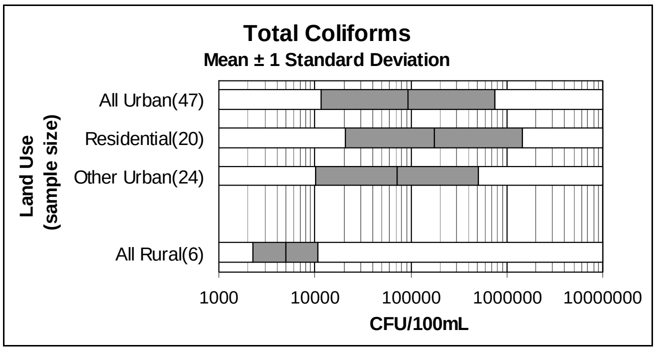

Total Chromium
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roads(9)
All Urban(64)
Residential(20)
Industrial(9)
Commercial(4)
Other Urban(31)
0.001
0.01
0.1
1
Concentration (mg/L)

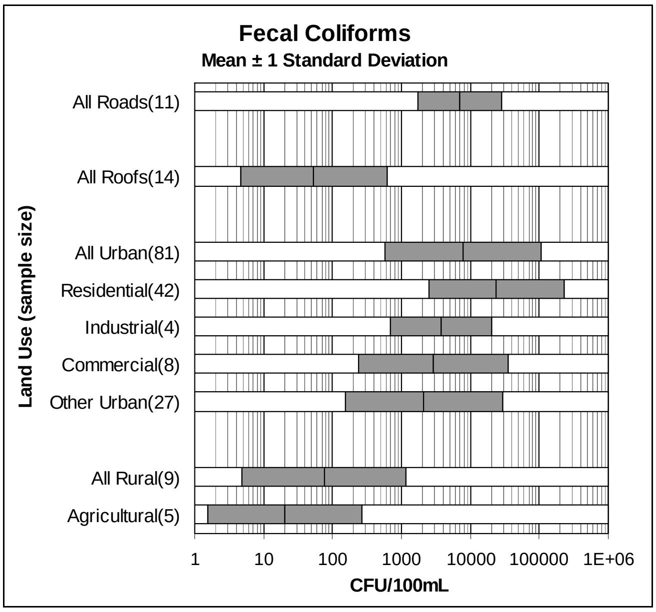

Total Nickel
Mean ± 1 Standard Deviation
Land Use (sample size)
All Urban(48)
Residential(11)
Industrial(5)
Other Urban(30)
0.001
0.01
0.1
1
Concentration (mg/L)

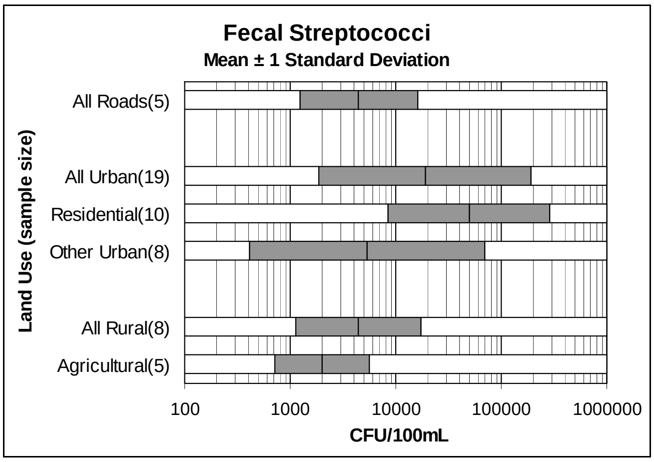

Total Iron
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roads(7)
All Urban(53)
Residential(25)
Industrial(5)
Commercial(8)
Other Urban(15)
All Rural(6)
0.1
1
10
100
Concentration (mg/L)

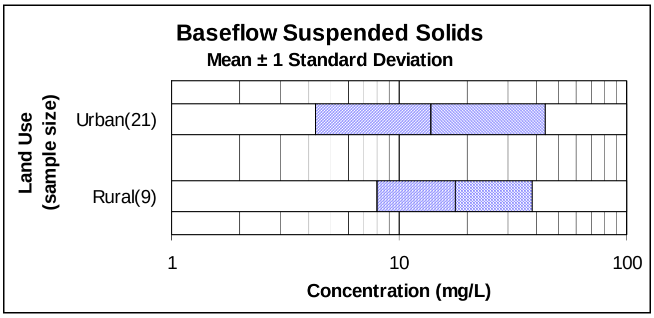

Total Manganese
Mean ± 1 Standard Deviation
Land Use (sample size)
All Urban(16)
Residential(5)
Other Urban(7)
0.01
0.1
1
10
Concentration (mg/L)

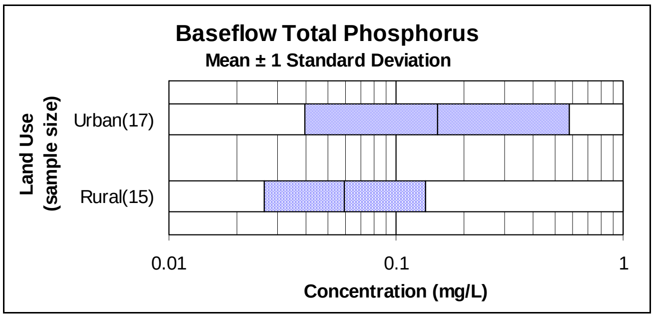

Total Mercury
Mean ± 1 Standard Deviation
Land Use (sample size)
All Urban(13)
0.00001
0.0001
0.001
0.01
Concentration (mg/L)

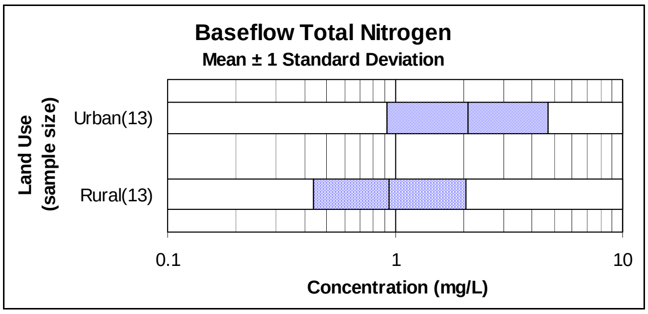

Total Coliforms
Mean ± 1 Standard Deviation
Land Use (sample size)
All Urban(47)
Residential(20)
Other Urban(24)
All Rural(6)
1000
10000
100000
1000000
10000000
CFU/100mL

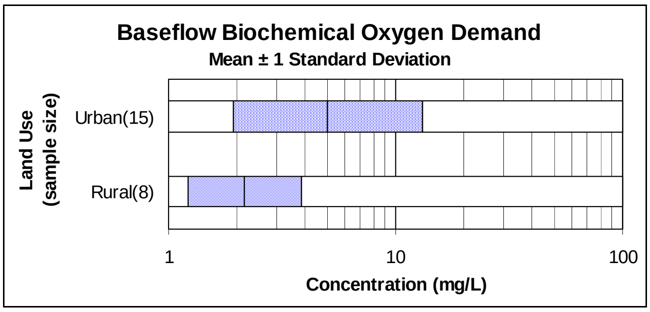

Fecal Coliforms
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roads(11)
All Roofs(14)
All Urban(81)
Residential(42)
Industrial(4)
Commercial(8)
Other Urban(27)
All Rural(9)
Agricultural(5)
1
10
100
1000
10000
100000
1E+06
CFU/100mL

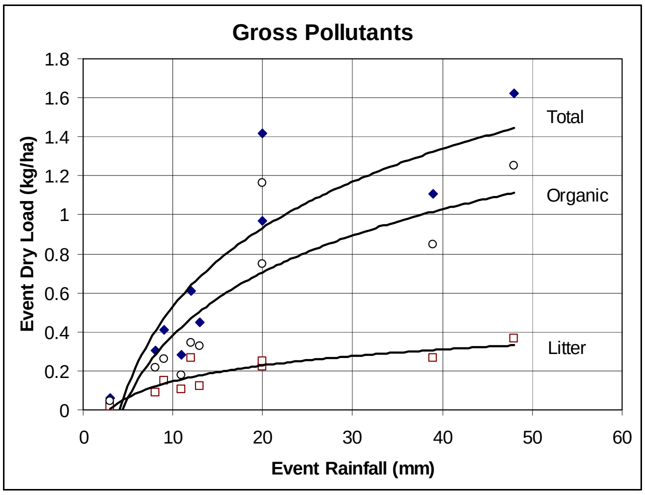

Fecal Streptococci
Mean ± 1 Standard Deviation
Land Use (sample size)
All Roads(5)
All Urban(19)
Residential(10)
Other Urban(8)
All Rural(8)
Agricultural(5)
100
1000
10000
100000
1000000
CFU/100mL


Baseflow Suspended Solids
Mean ± 1 Standard Deviation
Land Use (sample size)
Urban(21)
Rural(9)
1
10
100
Concentration (mg/L)


Baseflow Total Phosphorus
Mean ± 1 Standard Deviation
Land Use (sample size)
Urban(17)
Rural(15)
0.01
0.1
1
Concentration (mg/L)


Baseflow Total Nitrogen
Mean ± 1 Standard Deviation
Land Use (sample size)
Urban(13)
Rural(13)
0.1
1
10
Concentration (mg/L)


Baseflow Biochemical Oxygen Demand
Mean ± 1 Standard Deviation
Land Use (sample size)
Urban(15)
Rural(8)
1
10
100
Concentration (mg/L)


Gross Pollutants
Event Dry Load (kg/ha)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Total
Organic
Litter
0
10
20
30
40
50
60
Event Rainfall (mm)