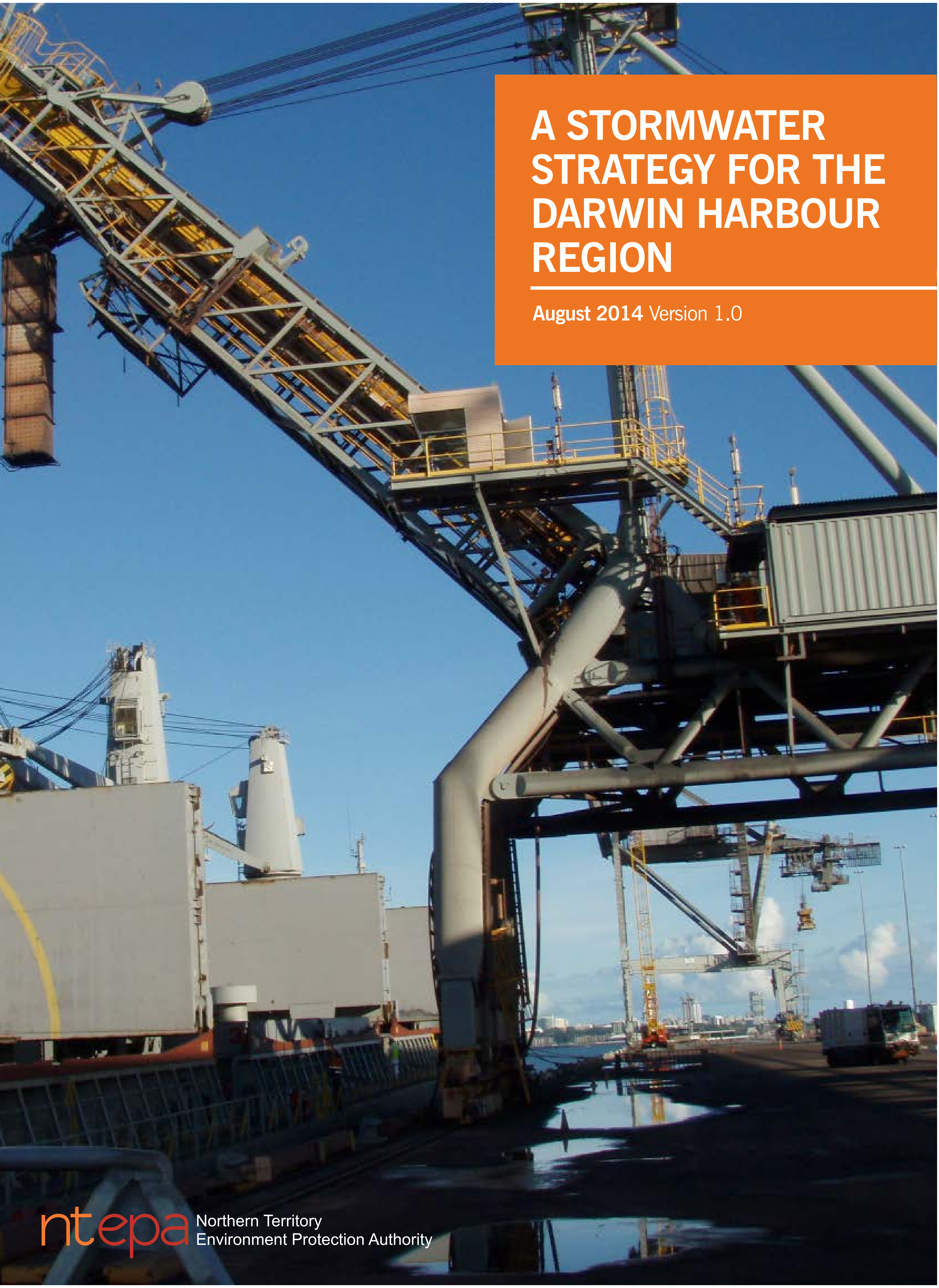


A STORMWATER STRATEGY FOR THE DARWIN HARBOUR REGION

August 2014 Version 1.0

Northern Territory Environment Protection Authority

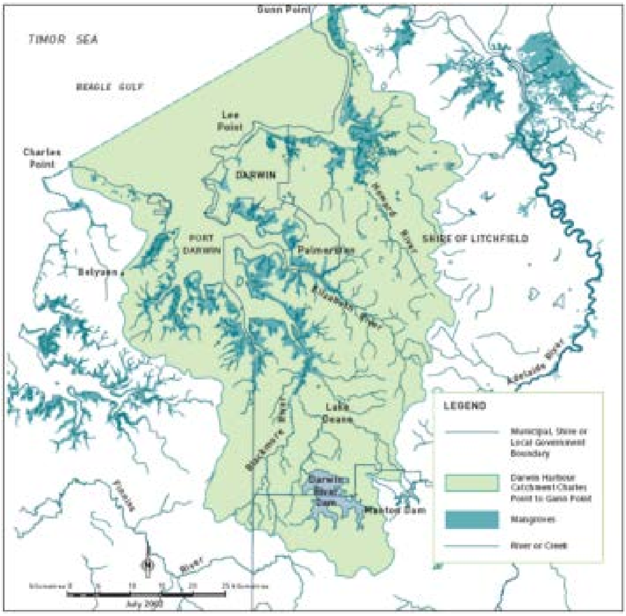
Northern Territory Environment Protection Authority
GPO Box 3675
Darwin
Northern Territory 0801

Important Disclaimer

CONTENTS

1.
PURPOSE

This Strategy provides a basis for improving management of the quality of stormwater entering Darwin Harbour (Figure 1). The actions are achievable within a relatively short period of time, and involve actions by the Northern Territory Environment Protection Authority (NT EPA) with the support and involvement of various industry, government agency, Local Government and community interests.



/ **Figure 1: The Darwin Harbour Region**

This Strategy will contribute to maintaining high water quality in the harbour. Other aspects such as limiting and managing industrial discharges, sewage effluent, shipping discharges to the harbour, dredging and illicit dumping of wastes will need progressive improvement. These issues are subject to existing regulation and will be addressed during forthcoming reviews of environmental legislation and ongoing development of policies, guidelines and practices.

This Strategy complements activities undertaken by the Department of Land Resource Management's (DLRM) long term research and monitoring program in the harbour, and the Darwin Harbour Water Quality Protection Plan including catchment management, water quality and bioindicator monitoring, and preservation of riparian ecosystems.

2. MANAGEMENT ISSUES

Stormwater is "water flowing over ground surfaces in natural streams and drains as a direct result of rainfall over a catchment" (ARMCANZ/ANZECC, 2000) and consists primarily of runoff from rainfall and any material (soluble or insoluble) mobilised in its flow path.

Darwin Harbour is a focal point for cultural, residential, commercial and industrial activity in the Darwin Harbour Region (Figure 1). It is a notable tourism destination, provides opportunities for employment as a "working harbour", represents a cultural and historical record of our past and present, and provides opportunities for a wide range of recreational activities.

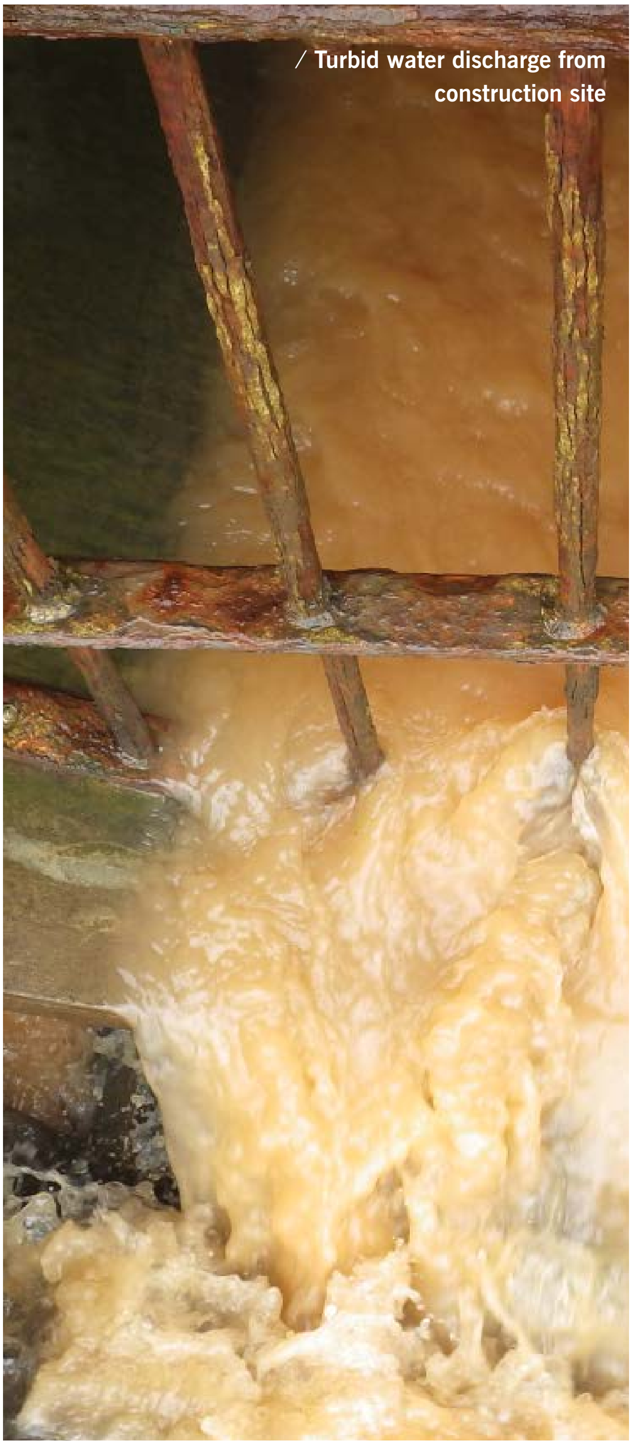
High water quality, including stormwater quality, is an essential element in the long term maintenance of the harbour's capacity to provide us with the amenity we currently enjoy.

The water quality of Darwin Harbour is regarded as being good in most places (i.e. a "healthy aquatic ecosystem"). This determination is based on long term monitoring of nutrients, dissolved oxygen, acidity-alkalinity, turbidity, and chlorophyll. There are no comparable data on metals, petroleum chemicals or other toxic chemicals (toxicants).

Darwin Harbour is not pristine. Our history of early European exploitation, periods of large anthropogenic disturbance and more recent modifications have caused long term impacts, with the potential for permanent change. Those changes include the beginnings of deterioration in the harbour's water quality. Zones of long term nutrient elevation and temporary blooms of algae and bacteria are evident, particularly in the less well flushed upper reaches of the harbour.

Stormwater runoff is a major contributor of sediment, nutrients and toxicants to pollution of the harbour. Sediment flows to the harbour are estimated to have more than doubled since European colonisation.

Stormwater discharges from Darwin urban environments are significantly greater than from rural areas. Urban discharges


/ **Turbid water discharge from construction site**

of sediment are estimated to be three times that of rural areas. Increases in other pollutants include three times for nitrogen, twelve times for phosphorus, greater than ten times for lead, zinc and copper, and three to seven times for other metals. The potential significance of land use is further indicated by the Darwin Central Business District (CBD) (0.39% of the catchment) contributing between 1 and 2% of the total pollutant loads of stormwater.

People are the fundamental source of the potential decline in harbour water quality. The ecologically sustainable development of the Northern Territory is critically dependent on continuing development of the Darwin Harbour Region and an expanding population. The population is predicted to expand from 128 100 in 2011 to 166 000 by 2025. Levels of pollutant output to the harbour will inevitably increase at a rate at least approximating the estimated rate of population increase i.e. approximately 2% per year. This rate of increase in pollutant output translates as a 10.6% increase in the five years to 2016, and a 22% increase in the ten years to 2021. Significant increase in pollutant load to the harbour will occur unless steps are taken to eliminate, reduce, reuse and recycle the wastes that our homes and industry produce.

The consequences of increasing pollution are clear and will likely parallel the rate of increase in pollutant input to the harbour. There is no threshold level of pollutant input below which all aspects of the harbour environment could be regarded as being in an acceptable condition, or above which all or even some aspects would be in unacceptable condition. Decline in the quality of the harbour environment would be gradual, with some aspects declining in condition before others. The patterns of decline of various aspects of the harbour environment cannot be readily determined and cannot be readily related to particular levels of pollutant input.

It is prudent to take steps to ensure that the Territory has the capacity and tools to appropriately manage sources of pollution and the quality of stormwater reaching the harbour. This is in keeping with the NT EPA Act's objective to promote ecologically sustainable development; a guiding principle of which is that where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. It requires pre-emptive action to mitigate the inevitably increasing pollution of ongoing development in the Darwin Harbour Region. It is easier to manage pollution in advance than to try and correct the damage once it has occurred. This will require steps to ensure improved:

- control of pollutants at point sources (e.g. building sites, discharges to stormwater, dumping);
- control of pollutants at diffuse sources (parks, homes, golf courses, roads); and
- treatment of stormwater pollutants.

Management improvements will necessarily need to provide the community with economically effective solutions i.e. reasonably practicable improvements.

3. OBJECTIVES

The objectives of the NT EPA in implementing this Strategy are to:

- remedy inadequacies in the regulatory framework;
- engage with the community, industry, local authorities and government agencies in improving stormwater quality;
- improve the capacity to monitor stormwater and respond to pollution events;
- provide government and the community with reporting on the progress of the Strategy; and
- undertake periodic, public reviews of the effectiveness or otherwise of the Strategy.

/ **Oil in drain; inappropriate practices**

4. MANAGEMENT ACTIONS

4.1 REMEDY INADEQUACIES IN THE REGULATORY FRAMEWORK

The NT EPA will conduct a review of the *Waste Management and Pollution Control Act* (WMPC Act). This will provide the public, industry, government and local government with a consultation paper examining the deficiencies and strengths of the WMPC Act's capacity to provide for soundly managed stormwater and other pollution and waste issues. The results of the consultation will be used to provide advice (under Part 3 of the NT EPA Act) to the Minister on amendments to the WMPC Act.

Matters relevant to stormwater management include:

- regulation and creation of offences related to inappropriate discharge of polluted matter/water to stormwater systems (e.g. intentional, negligently, not placing bungs in rubbish skips etc);
- providing local authorities with an enhanced ability to manage stormwater;
- approvals and licencing for a larger range of potentially polluting industries;
- formalisation of the role of Environmental Management Plans;
- possible changes to the regulation of illegal dumping; and
- improved coordination of responsibilities under the *WMPC Act and the Planning Act.*

4.2 ENGAGE WITH THE COMMUNITY, INDUSTRY, LOCAL AUTHORITIES AND GOVERNMENT AGENCIES IN IMPROVING STORMWATER QUALITY

The NT EPA will implement a program of consultation with the community, industry, local authorities and government agencies to:

develop facts sheets/guidelines on stormwater issues in the home, and management of homes, to reduce impacts on stormwater quality (e.g. how best to fertilise your garden, where to wash your car, disposal of electronic gadgets and appliances, dealing with waste from servicing your car, disposal of swimming pool backwash water and of noxious household chemicals such as left-over paint, solvents etc.);

- negotiate adoption of industry endorsed guidelines of pollution management where possible;
- develop guidelines for large to small businesses on stormwater management issues, in collaboration with industry associations and individual businesses;
- seek efficient and cost effective solutions to treatment of stormwater;
- publicise records of offences such as illegal dumping, inappropriate management of facilities and discharges to stormwater;
- provide active, ongoing NT EPA contact and interaction with industry associations and businesses;
- develop stormwater, waste and pollution themes for events and other actions; and
- develop waste and pollution as a key focus for the Environment Grants program.

As required by the NT EPA Act, all fact sheets, guidelines and other documents will be provided to the community, industry, local government and government agencies for input prior to being finalised.

4.3 IMPROVE CAPACITY TO MONITOR STORMWATER AND RESPOND TO POLLUTION EVENTS

Monitoring of stormwater quality and enforcement of illegal pollution incidents by the NT EPA will be enhanced by:

- cooperative development with local authorities of a Geographic Information System database that maps the stormwater system of the Darwin Harbour Region (including outfalls and access points for sampling), on-site wastewater systems, wastewater treatment plants, sewage mains and outfalls, stormwater retention ponds, known contaminated and rehabilitated contaminated lands, and the locations of potential major polluters;
- development of an active program to monitor stormwater and respond to pollution of stormwater in collaboration with local authorities.

4.4 PROVIDE GOVERNMENT AND THE COMMUNITY WITH REPORTING ON THE PROGRESS OF THE STRATEGY

The NT EPA Act requires the NT EPA to provide an annual report on its activities to the Minister. An update on progress in implementing each of this Strategy's management measures will be provided in that report.

4.5 UNDERTAKE PERIODIC, PUBLIC REVIEWS OF THE EFFECTIVENESS OR OTHERWISE OF THE STRATEGY

This Strategy will be reviewed and as appropriate renewed within five years.

/ Illegal waste water discharge into drain

APPENDIX A – BACKGROUND

This background material lacks formal referencing of statements and information to particular source material. This is contrary to usual scientific practice, but has been employed to help improve the readability of the document for lay people. The information used comes from a large number of sources listed in “Further Reading” at the end of the document. Scientific terminology has been minimised.

1.
THE STATE OF DARWIN HARBOUR

Darwin Harbour has been regarded as a relatively pristine environment, but it is no longer pristine. Changes from its pristine condition include extermination of the once extensive pearl shell communities during the early twentieth century, the impacts of World War II (which include the sinking of numerous ships, destruction of aircraft, oil spills, direct impacts from bombing), commercial fisheries, amateur and subsistence fishing and gathering, the impacts of dredging (to alter the contours of the harbour bottom and margins), discharges of sewage and wastes, enhanced inputs of sediment (as a result of spreading urban, industrial and agricultural developments in the catchments of the harbour), industrial spills of various materials, spills during ship loading, illicit dumping of wastes, pipelines, submarine cables, sinking of ships to create artificial reefs for amateur fishing purposes, wharf and marina developments and the ongoing impacts of human presence in and around the harbour. Changes to the composition of the communities of fish, crustaceans, corals, seagrasses, mangroves and the other elements of the harbour's biodiversity cannot be quantified. The harbour has had, and will continue to face, significant changes and impacts as development necessarily occurs.


/ Sediment from construction site

Water quality in Darwin Harbour has likewise been described as very good. This assessment is based on relatively recent water quality data. The quality of water in the harbour is generally high (i.e. a "healthy aquatic ecosystem") when compared to the ANZECC & ARMCANZ 2000 national guidelines for water quality. Water quality monitoring has been undertaken for some considerable time in Darwin Harbour and its catchment by the Power and Water Corporation, the Darwin International Airport Corporation, the aquaculture industry and other industrial concerns. Most importantly, the Northern Territory Government's Department of Land Resource Management (DLRM) has monitored water quality since 1986. Since 2009 DLRM has released annual overviews of water quality in the harbour known as the Darwin Harbour Report Cards. The 2009 Report Card provided a water quality assessment back to 2001. Data recorded include nutrients, dissolved oxygen, turbidity, chlorophyll contents and acidity-alkalinity. There are no equivalent data systematically documenting metals and other toxic pollutants (toxicants).

There are indications of a decline in water quality in some areas. These signs include zones of long term nutrient elevation and temporary blooms of algae and bacteria. Other signs of nutrient/toxicant enrichment such as macro-algal blooms or high levels of metals in fish have not been detected. These can be expected to occur unless the quality of water entering the harbour is maintained.

The consequences of potential declines in water quality are extensive including:

- enhanced nutrient concentrations leading to:
  - » toxic algal and bacteriological blooms
  - » enhanced growth of epiphytes (organisms that grow on other organisms) that smother corals and seagrasses
  - » expansion of macroalgal populations that when eaten by marine turtles promote debilitating fibropapilloma virus infections (giant wart like growths), as has occurred in eastern Queensland and many parts of the world in recent years
  - » loss of marine habitats
- excessive levels of minerals and other toxicants leading to:
  - » accumulation of toxic chemicals in fish and other food and non-food animals
  - » potential for mortality of fish and other organisms
  - » decline and loss of marine habitats
- decline in harbour biodiversity
- reduced recreational amenity
- local decline in fishing
- reduced attraction for tourists.

Parts of Darwin harbour are inherently vulnerable to these and other environmental risks.

It is timely to ensure that effective planning and management are in place to ensure retention of high water quality in the harbour.

2.
THE VULNERABILITY OF DARWIN HARBOUR TO FUTURE POLLUTION

Darwin Harbour's vulnerability to future pollution is a function of three primary factors:

- the population of humans;
- the geomorphic and hydrological characteristics of the Darwin Harbour Region; and
- future growth in sources and types of pollution.

2.1 POPULATION

The population of Darwin, Palmerston and Litchfield was 128 100 people in June 2011. The Australian Bureau of Statistics 2013 report indicated that the Darwin Region accounted for three-quarters of the Northern Territory's population growth between June 2010 and June 2011, and was home to 56% of the Territory's population in 2011.

Recent work by the Northern Territory's Department of Treasury and Finance indicates that the population of the Darwin Region is projected to increase to 166 000 persons by 2025 (approximately a 2% increase per year).

People are a fundamental source of pollution. We all generate pollution as a consequence of our everyday existence and needs. Growth in population will lead to an inevitable increase in future levels of potential pollution in the Darwin Harbour Region. The rate of increase in pollutants entering the harbour will approximate the rate of population growth (i.e. 2% per year).

Existing land uses of the Darwin Harbour Region, as percentages of the area, are provided in Table 1 below. The area subject to intensive development is relatively small. A large proportion of the unconstrained, undeveloped area will be subject to intensive development over the coming years.

The expanding area of intensive development as a direct result of population growth will spread the sources of pollution over a larger area of land. It will also result in pollution entering the harbour from an expanding number of locations. The harbour's waters will inevitably be subject to levels of nutrient and toxicant pollution that potentially increase in parallel with growth of the human population. The levels of increase need to be managed.

Land Use	Percentage
Undeveloped	70
Urban and other intensive land-uses	13
Grazing natural vegetation	3
Agriculture	6
Water (Darwin River Reservoir) and wetlands	8

/ Table 1: Land Uses in the Darwin Harbour Catchment

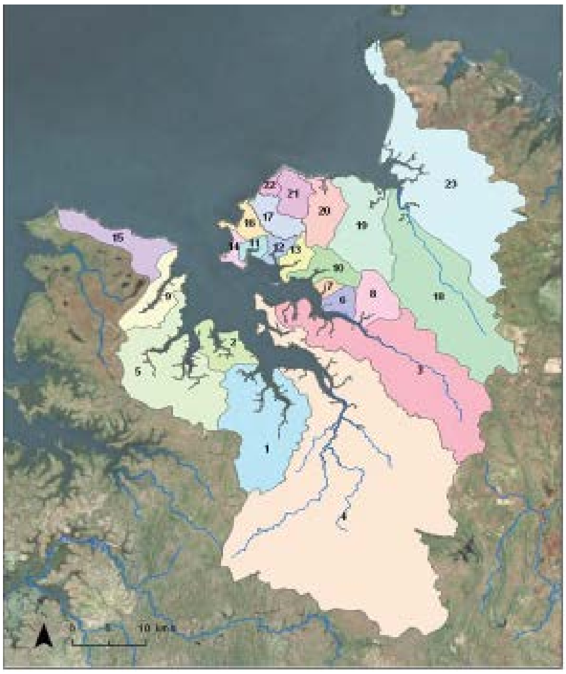
2.2 THE CHARACTERISTICS OF DARWIN HARBOUR

Darwin Harbour's (Figure 1) vulnerability to pollutant damage is determined by an interaction among factors that provide inherent protection from pollutants, and factors that act to increase its vulnerability to potential pollutant impacts. Factors providing inherent protection from pollutant impacts include its surface area and volume, tidal regime and catchment size. The several rivers and many small streams entering the harbour over its extensive coastline provide many entry points for stormwater pollutants, creating a complex management situation that may increase its vulnerability to pollution.

Darwin Harbour's vulnerability to pollution is lowered by its having a relatively large surface area relative to its volume, and large tidal movements. The harbour is a 1 220km^2 embayment at the highest astronomical tide and is classified as a tide-dominated estuary with large tidal movements. The maximum tidal range is 8.0 metres (m) with mean spring and neap ranges of 5.7 m and 1.8 m. The volume of Darwin Harbour between East and West Points more than triples between spring mean high and low tides. The large tidal movements produce strong currents that transport sediment and other pollutants within and across the harbour's boundaries, effectively flushing much of the harbour on a regular basis. In contrast the upper parts of the harbour are not well flushed, with an average residence time of approximately 20 days.

Darwin Harbour is protected from the input of pollution by having a small catchment area relative to its estuarine area. The catchment to estuary area ratio is 3:1, smaller than other Australian harbours such as Port Phillip Bay (4:1), Port Jackson (10:1), and Moreton Bay (14:1). This means that the water in Darwin Harbour would be less polluted than other harbours listed if there were equivalent levels of pollutant input per unit area of catchment. The relatively small catchment results in a total annual inflow into Darwin Harbour that approximates the volume of the harbour. The estimated maximum recorded cumulative catchment discharge into the harbour during a flood is equivalent to only about 1% of the peak spring tide discharge. The pollutant content of stormwater flows would be well diluted on reaching the outer harbour.

In contrast, the inherent vulnerability of Darwin Harbour is enhanced by the several rivers and many small streams flowing into it. Estuaries of some other large cities in Australia (e.g. Perth, Brisbane) receive catchment inflow predominantly from just one large river. The Blackmore River catchment, at about 35%, is the largest sub-catchment of Darwin harbour and flows into Middle Arm (Figure 2). Next ranked are the Elizabeth and Howard Rivers which each drain about 10% of the harbour's catchment. In addition there are small streams which flow into Darwin Harbour along its extensive shoreline length of approximately 760 km. There is a diverse range of locations for potential pollutant input into the Darwin Harbour.



/ Figure 2: Sub-catchments of the Darwin Harbour Region

1 Pioneer Creek (6.4%); 2 Creek A Middle Arm (1.4%); 3 Elizabeth River (10.3%); 4 Blackmore River (35.2%); 5 West Arm (6.5%); 6 Palmerston South (0.6%); 7 Myrmidon (0.3%); 8 Mitchell Creek (1.6%); 9 Woods Inlet (1.8%); 10 Hudson Creek (1.2%); 11 Sadgroves Creek (0.4%); 12 Reichardt Creek (0.5%); 13 Bleesers Creek (0.7%); 14 Darwin CBD (0.4%); 15 Charles Point (2.2%); 16 Ludmilla Creek (0.7%); 17 Rapid Creek (1.2%); 18 Howard River (9.3%); 19 Kings River (3.8%); 20 Micket Creek (1.8%); 21 Buffalo Creek (1.1%); 22 Sandy Creek (0.3%); 23 Gunn Point (12.3%)

There is potential for pollutants to accumulate in particular areas of the harbour. Darwin Harbour is an inverse estuary during the Dry season with high salinity in the upper reaches due to evaporative concentration and poor flushing with oceanic waters. The absence of large scale mixing would act to concentrate and maintain higher levels of pollution in the upper arms of the harbour.

The geomorphology, hydrodynamics and catchment characteristics of Darwin Harbour interact to provide some security from potential impacts from pollution in the outer harbour, while causing significant potential for impacts in the upper reaches. These areas of potential pollutant concentration are those most likely to receive increasing input of pollutants as development progresses.

2.3 SOURCES OF STORMWATER POLLUTANTS

Potential pollutants to stormwater and their sources are summarised in Table 2.

Pollutant	Source
Sediment	Land surface erosion, pavement and vehicle wear, atmospheric deposition, spillage/illegal discharge, organic matter (e.g. leaf litter, grass), car washing, weathering of buildings/structures.
Nutrients	Organic matter, fertilisers, sewer overflows/septic tank leakage, animal/bird faeces, human excreta, detergents (car washing), atmospheric deposition, spillage/illegal discharge.
Oxygen demanding substances	Organic matter decay, atmospheric deposition, sewer overflows/septic tank leaks, animal/bird faeces, spillage/illegal discharges.
pH (acidity)	Atmospheric deposition, spillage/illegal discharge, organic matter decay, erosion of roofing material.
Micro-organisms	Animal/bird faeces, human excreta, sewer overflows/septic tank leaks, organic matter decay.
Toxic organisms	Spillage/illegal discharge, sewer overflows/septic tank leaks.
Gross pollutants (litter and debris)	Pedestrians and vehicles, waste collection systems, littering, leaf-litter, lawn clippings, spills and accidents.
Heavy metals	Atmospheric deposition, vehicle wear, sewer overflows/septic tank leaks, weathering of buildings/structures, erosion of roofing material, spillage/illegal discharges.
Oils and surfactants	Asphalt pavements, spillage/illegal discharges, leaks from vehicles, car washing, organic matter.
Other toxicants	Pesticides, herbicides, industrial spillage and leaks, sewage overflows, atmospheric deposition.
Increased water temperature	Run-off from impervious surfaces, removal of riparian vegetation.

/ **Table 2: Potential Stormwater Pollutants and Their Sources**

Sources of pollution are frequently classed as point sources and non-point sources. Point sources are usually viewed as having a particular location from which discharges to the environment occur over lengthy periods of time. Examples include discharges from sewage treatment facilities, and industrial discharges that can be regulated under the WMPC Act and *Water Act*. Significant, long term discharges from point sources should not be discharged to stormwater.

Non-point sources of pollution are often termed diffuse sources. These are often associated with particular land uses or are illicit or unintended discharges resulting from spills or leaks that ultimately enter ground and/or surface water. Diffuse sources are the major source of pollutants to stormwater.

Diffuse sources of pollutants are wide spread and produce discharges that are difficult to attribute to a specific clearly defined location, and individually may not necessarily be sufficient or significant enough to be subject to licencing. Pollutants from diffuse sources are usually accumulated in run-off during and after periods of rain, are disposed of via stormwater systems, and move to drainage lines or reach the harbour via surface flows of water.

Sources of diffuse pollution include road and pavement surfaces, agricultural fields, golf courses, public and private lawns and gardens, rooves, cars, leaking waste containers, land clearing, small businesses, food wastes, construction sites, illegal dumping or result from human or animal excrement (faeces or urine) being deposited in inappropriate locations.

Spills and leaks provide unquantified contributions to the pollutant loads entering the harbour in stormwater. Spills and leaks are of unpredictable occurrence and duration. They are an important component of diffuse source pollution. Spills have included copper concentrates at East Arm Port in 2010, petroleum/oil related spills and spills evident from sediment analyses in some parts of the harbour. There have been leaks from service stations, major fuel storages and municipal waste storage and disposal locations. The leaks may be to surface water leading to the harbour, or to groundwater that reaches or potentially reaches the harbour. These issues are expected to increase as inevitably more spills occur and more leaks are detected as the population grows. Leaks causing land contamination is an emerging issue in the Darwin Region.

Many small businesses allow discharges to the environment that end up in the stormwater system. Examples include waste skips (from which the bungs have been removed) and/or waste skip wash down areas; food shops or outlets; motor vehicle and equipment repair and service locations; small scale manufacturers; car washes; and high pressure cleaning. There are also cases of deliberate and long term release of polluting materials to stormwater, and poor business planning that fails to predict or manage pollutant discharges. The significance of these discharges has never been quantified or evaluated. Existing data include these discharges in general assessments of discharges to the harbour.

Spills and leaks need to be included in any approach to the management of stormwater quality in the Darwin Region.

Stormwater may contain a diverse assemblage of pollutants. The pollutants include gross pollutants (litter), nutrients, sediment and toxicants. Gross pollutants encompass a wide variety of materials including drink containers, toys, paper and cardboard packaging, plastic bags, other plastic objects and dead animals as well as leaf litter, cigarette butts and pieces of wood. Gross pollutants frequently enter the stormwater system during ‘first-flush’ events and continue to a lesser extent as the wet season progresses.

Toxicants include the full spectrum of metals, hydrocarbon products, biocides (e.g. insecticides), acids, strong alkaline material, surfactants (e.g. detergents), pharmaceuticals, and a wide variety of chemicals used in industry. Low concentrations of pesticides have been detected in waterways entering Darwin harbour, most frequently from urban catchments rather than the rural hinterland. 20 years of pesticide investigations found that the most common pesticides of the 34 detected were organochlorines (DDT, DDE and dieldrin) used for control of termites. These chemicals are no longer available due to problems of persistence in the environment. Other toxicants originate from spills and illegal dumping of a range of materials.

2.4 POLLUTANT INPUT TO DARWIN HARBOUR

Levels of point and diffuse source discharges of nutrients (nitrogen and phosphorus) and sediment to Darwin Harbour are relatively well understood, and provide a basis for assessing the significance of pollutant loads relative to natural inputs. Data are available on discharges of some toxicants (metals) in stormwater.

Human activity has approximately doubled nitrogen loads into Darwin Harbour, and has resulted in a seven fold increase in phosphorus loading. The increase in phosphorus load largely originates from wastewater from sewage plants, whereas the majority of the nitrogen increase is directly attributable to stormwater. The high levels of phosphorus in sewage effluent are caused by the relatively higher efficiency of removing nitrogen during treatment.

It was estimated that approximately 39% of the nitrogen (along with 11% of the phosphorus) exported during the wet season comes in groundwater flows. The source of these nutrients is uncertain, but may be to some extent related to risks associated with unregulated septic discharges and leaking sewers.

/ **Significant quantities of oil dumped in waterway**

While seemingly large, these increases in nutrient input to the harbour are relatively minor in comparison to natural source inputs. The major natural source of nitrogen and phosphorus (15 015 and 1 087 t yr^{-1} respectively from tidal flushing) is many times greater than sewage inputs (180 and 49 t yr^{-1} respectively). This overall impression of relatively low levels of nutrient pollution does not apply to some less well flushed areas of the harbour.

Sediment from catchment runoff and Sewage Treatment Plants (STP) have approximately doubled annual loads to the harbour. Urbanisation results in an eight fold increase in the amount of suspended sediment exported annually per unit area. Most of this is silt and other inorganic material with a smaller portion (~20%) of organic matter. STP sources are mainly organic (69 - 94%), and constitute a minor portion (5%) of the total human generated load.

2.4.1. Urbanisation and Stormwater Pollution

Analysis of hydrographic and rainfall data from four sub-catchments within the greater Darwin Harbour Region found that:

- urban catchments have higher runoff coefficients (proportion of rainfall that runs off the surface rather than being absorbed by the land surface) relative to rural catchments; and
- runoff coefficients increase as annual rainfall increases.

Urbanised areas of a catchment produce a greater proportion of runoff, and this proportion increases as total rainfall increases. Urban land-use approximately doubles the annual run-off co-efficient which varies with annual total rainfall. More specifically, the proportion of impervious surfaces (as the result of urbanisation) exacerbates run-off by reducing infiltration to groundwater.

Land area, rainfall patterns and land use types have a profound influence on the quantitative and qualitative composition of pollutants in stormwater. Predicted annual pollutant loads entering Darwin Harbour are directly proportional to the annual rainfall i.e. the greater the rainfall, the greater the pollutants entering the harbour. The largest contribution of pollutants in general is made by the largest catchments (i.e. the Blackmore and Howard Rivers, 44.5% of the catchment). The potential significance of land use is also indicated by the Darwin CBD (0.39% of the catchment area) contributing between 1 and 2% of the total pollutant loads. If the Blackmore and Howard River catchments were discharging pollutants at the same rate as the CBD the rivers would discharge additional pollutants equivalent to up to 228% of the total existing pollutant input to the harbour.

Discharges from the rural area and the undeveloped area in the catchments are similar. The urban area exhibits significantly enhanced discharges of nutrients (nitrogen and phosphorus). Discharges of metals are substantially higher in the urban area.

Expanding areas of development around the harbour will inevitably result in increasing levels of discharge of stormwater and other pollutants to the harbour. Increasing impacts on harbour water quality will be most notable in poorly flushed upper parts of the harbour.

3.
STORMWATER MANAGEMENT

3.1 OBJECTIVES AND DESIGN OF STORMWATER MANAGEMENT SYSTEMS

The primary imperatives in the design and operation of existing stormwater systems are:

- flooding and drainage control; and
- human health and safety.

This was traditionally achieved by designing stormwater systems to remove water from an area as quickly as possible, eliminating areas of standing water.

These requirements must in all circumstances remain as primary considerations in stormwater management. This can be achieved in concert with the achievement of other objectives integral to sustainable development i.e. maintenance of ecosystems, human health, social, economic and development opportunities and aesthetic appeal; which are largely a function of the maintenance of high water quality.

Minimisation of damage to people and property caused by infrequent, yet often intensive rainfall events, and reduction in health problems from disease vector populations (mosquitoes) and ponding of putrid water are achieved by minimising the effects of peak flows and ensuring well drained catchments. This can be predicted using catchment and subcatchment hydrological models based on an area's topography, natural drainage patterns and previous patterns of rainfall. Models predict the potential for flood generation and estimate patterns and rates of flow within the context of the natural and proposed developed environments.

Design of stormwater systems uses the model outputs to provide what could be described as two interconnected systems. One, a minor system is designed to collect rainfall from roads, streets, gutters, roadside ditches, rooves, parking lots etc., and channel water to a major system. The major system carries water via natural drainage lines, large man-made conduits, and water impoundments. The minor system is often designed for less intense rainfall events than the major system, which must be capable of removing water from multiple sources to eliminate potential for flood damage. The major system can include large swales and temporary ponding to slow flow rates. Slowing flow rates can be critical to avoiding overload of the major system, and damage that may result to infrastructure e.g. damage to streamlines, bridges, roads and other property from flooding. An estimated 80% of sediment input to Darwin harbour comes from the erosion of stream channels. The two systems must be designed in accordance with current standards.

The Australian Guidelines for Urban Stormwater Management (ARMCANZ/ANZECC, 2000) highlight the fact that controlling flooding and drainage and maintaining public health are not divorced from the need to achieve other objectives. These include maintenance of natural ecosystems (aquatic and terrestrial components), social factors, recreational opportunities and aesthetic values. All these objectives are inextricably linked to the maintenance of water quality.

It is critically important that designs for stormwater management be economically achievable. This can be achieved by designing systems that have water quality management features that are:

- components of (i.e. complement) the management of flooding and impacts on human health and convenience; and
- are effective, efficient and, can be economically managed.

3.2 CONTROL OF POLLUTANTS AT POINT SOURCES

The most effective means of limiting contamination of stormwater is the control of pollutant release at its source. This relates to both point source and diffuse sources of pollution.

3.2.1. Erosion and Sediment Control

Effective management of erosion and sediment on building and other sites is important in limiting sediment discharge to the harbour. Levels of sediment loss from areas under construction are in the order of 100 to 1 000 times greater than those observed following completion of construction and establishment of landscaping. The quantity of sediment leaving construction areas can amount to as much as 300 tonnes per hectare as was recorded from a Sunshine Coast (Queensland) development.

Release of sediment from building sites to stormwater may be regulated under the *Water Act* and WMPC Act, and may be subject to approval conditions under development permits issued by the Development Consent Authority under the *Planning Act*. The *Water Act* is only applicable if discharges are directly to water in natural waterways, to groundwater or to tidal water. Stormwater drains are not waterways. The WMPC Act does not licence or approve discharges for most building operations. In the absence of pre-emptive measures NT EPA relies primarily on Pollution Abatement Notices and infringement notices under the WMPC Act in response to discharges.

The Northern Territory Planning Scheme provides broad requirements and objectives for development approvals. The scheme provides direction for retention of riparian areas, and requirements for stormwater management, pollution and sedimentation in relation to some lands. These requirements are primarily restricted to zoned areas and contain omissions such as not applying to building operations (only civil works), or building of roads and utilities.

Activities approved under the *Planning Act* may require an Erosion and Sediment Control Plan/Environmental Management Plan for civil works. Enforcement of these provisions of the development approvals is difficult, usually requiring recourse to use of the WMPC Act as described above. Local authorities have by-laws relevant to the issue but these do not seem adequate to manage and regulate pre-emptive Erosion and Sediment Control Plans.

The absence of controls over erosion and sedimentation from building sites and omissions from the Planning Scheme are significant risks to pollution of Darwin Harbour and need remedying.

3.2.2. Discharges Directly to Stormwater

Discharge of polluted water to water in a waterway, or to groundwater or tidal water is contrary to the *Water Act*. A stormwater drain is not classed as a waterway and there are no effective ways to regulate and ensure prevention of purposeful, negligent or incidental discharges to stormwater drains.

These forms of pollution occur from waste skips and small and large businesses every day. The discharges are individually too small and insignificant to licence, but cumulatively potentially large. The high levels of pollutants in stormwater from the Darwin CBD are partially related to this mode of pollutant input, along with inappropriately deposited human excreta. The release of these pollutants is relatively easily prevented.

There are cases of medium and large sized licensed premises discharging to stormwater. This is likely to be occurring from similarly sized businesses not subject to licensing that would allow them to be aware of and integrate pollutant management into their processes and business planning.

3.2.2.1. Inappropriate Dumping

Inappropriate dumping of sewage, sullage and septic fluids, oil and other petroleum products, paint, building materials and other industrial and domestic wastes regularly occurs over the Darwin Harbour Region. This is illegal and subject to significant penalties under the WMPC Act and/or *Water Act*. This behaviour singly or in total has the potential to detract from the aesthetic qualities of Darwin harbour, harm its ecosystems and potentially impact on people and the local economy. It is also unethical in terms of equitable competition among businesses in the same industry when some participants purposefully avoid their legal obligations to prevent pollution or environmental harm.

3.3 CONTROL OF POLLUTANTS FROM DIFFUSE SOURCES

3.3.1. Parks, Golf Courses, Homes and Gardens

These land uses result in significant cumulative inputs of pollutants to Darwin harbour; nutrients and toxicants. There is no existing regulatory capacity to lower these inputs. Effective regulation is likely to be next to impossible to develop and implement. Other than large parks, gardens and golf courses, no individual source is, of itself, usually capable of causing a significant problem. It would be next to impossible to relate discharges from a single large diffuse source to an observed rise in harbour nutrients/toxicants.

An industry and community education program, development of guidelines for appropriate management of these discharges (including accreditation of industry specific guidelines) and non-licencing forms of regulation to allow local authorities to manage inputs to their stormwater systems are necessary.

/ Anoxic material dumped in waterway

3.3.2. Streets and Roads

Streets, roads and their verges are major accumulators and transporters of pollutants. The pollutants include a mix of sediment, particles derived from tyres, hydrocarbons, and a variety of metals, along with a mix of nutrients, and other toxicants gained from atmospheric deposition and water flows from urban and industrial or other areas.

Roads are designed to provide adequate drainage under the pavement, and shed water rapidly. Grassy verges and large swales have the capacity to slow flows and reduce the volume of stormwater leaving road areas and aid in stormwater management in terms of flood mitigation and water quality management (see under stormwater treatment).

Stormwater systems under roads and on road verges belong to the owner of the road, and are frequently linked to stormwater systems with a different ownership. The Road Network Division of the Northern Territory Department of Transport is the primary agency responsible for regulating stormwater discharge through government owned road corridors, including roads outside of urban centres or in areas owned or developed by the Land Development Corporation. The Northern Territory road network comprises the National Highways, arterial and local roads and bridges in the Territory, except for those owned by local government.

The *Control of Roads Act* provides the power for managing stormwater drainage of roads. Section 54 of the Act prohibits a person from permitting the discharge of:

> "effluent from a septic tank,
> dirty water, filth, dirt or other
> offensive matter, fluid or thing
> to run or flow on to a road
> from a house, land or premises
> occupied by that person".

The above provision offers some stormwater pollution prevention but the primary intention of the provision is the maintenance of road reserve amenity rather than an intention to maintain good stormwater quality to receiving waters.

3.3.3. Preservation of Riparian Ecosystems

Natural drainage systems are essential components of stormwater systems. Removal of riparian vegetation (vegetation along waterways) can significantly increase run-off from rain, increase overland flows, decrease infiltration to ground water and increase the rates and volumes of flow in streams and rivers. This can exacerbate flooding potential; compounding the problems of stormwater management. It may dramatically increase the potential for surface erosion, channel scouring and high pollutant loads, reducing the long term sustainability of stormwater systems discharging to waterways. Sustainability of waterway discharges of stormwater is also reduced by excessive and/or poorly controlled discharges from conduits and pipes.

Natural wetlands may serve as retention zones, slowing flows to channels and providing an opportunity for settlement of suspended sediment and pollutants. Poor management of riparian areas and wetlands can reduce their effectiveness in reducing stormwater impacts.

The Northern Territory has land clearing guidelines prescribed under the *Planning Act*. These recommend retention of buffers of native vegetation along water courses and around permanent and seasonal wetlands, lagoons and billabongs. Retention of larger areas of natural vegetation is regulated according to the Darwin Regional Land Use Plan and Area Plans developed under the *Planning Act*. The clearing guidelines do not apply to residential or industrial subdivisions.

Alteration and disturbance of waterways is regulated by DLRM under the *Water Act*.

3.4 TREATMENT OF STORMWATER

3.4.1. Methods of Stormwater Treatment

The longest established stormwater treatment is the provision of simple gross pollutant traps and sediment traps. These, if maintained, can be effective and fundamental to the efficient operation of standard stormwater systems, as in the Darwin Region.

Other methods are based on:

- reducing the volume and flow rate of stormwater so as to reduce the level of pollutants collected and carried by runoff e.g. domestic rainwater tanks, promotion of infiltration to groundwater, use of grey water (bath, sink and clothes washing water);
- fine filters that remove particles finer than gross pollutants;
- reducing the rate of flow of stormwater to allow for settlement of sediments, adsorption, absorption, biological degradation and chemical transformation of nutrients, metals and other toxicants, and reduction of erosion in watercourses; or
- a combination of the preceding methods.

The large volumes of stormwater in the Darwin region preclude consideration of prohibitively expensive osmotic or ion exchange processes. Detailed consideration of infiltration systems is not provided because of limitations imposed by high levels of waterlogging of soils during the Darwin region's high rainfall and long Wet Season.

Standard approaches using the methods listed above include: bioretention systems; grassy swales; and artificial wetlands of various sorts. Each of these approaches is briefly described and information provided on the limited field data available of achieved (as opposed to modelled) levels of performance. The only partially relevant data found are from one study in a sub-tropical area: the Gold Coast, Queensland.

Bioretention systems function by channelling stormwater (following sediment reduction) through vegetation and then a filter medium. The water is collected in a drainage system under the media and passed to the downstream stormwater system. The system is lined to prevent water loss or, in certain circumstances the filtered water may be allowed to infiltrate the soil (i.e. in the absence of waterlogging or potential to cause pollution of groundwater). These systems can be placed in large open areas or even on roadsides in urban settings. All these systems have a bypass system for dealing with high flow rates. Nutrients and metals are removed through adsorption to vegetation and media particles, biotransformation, and absorption by plant roots. The ponds are in the order of 0.2 to 0.4 m deep and designed to completely drain between storms.

It is uncertain how effective bioretention systems would be under Darwin conditions with possibly incomplete drainage between storms, and loss of vegetation during the Dry season potentially lowering the efficiency of pollutant removal.

Grassy swales are large open drains with relatively wide, flat bottoms and a low slope. Swales take the place of or are implemented in conjunction with standard stormwater pipe systems. The low grades help to slow the stormwater allowing coarser sediments to settle among the grasses. To be effective the drains need to treat over 90% (there is an estimate of 80% for Darwin although the basis of the estimate is uncertain) of a catchment's stormwater. In Darwin this has been estimated to mean that it would need to treat half of the average one in one year return interval flow. These systems should be viewed as removing coarse sediment, and are often used as pre-treatment before bioretention systems or artificial wetlands. The long

Dry season would reduce the grassy cover, reducing the effectiveness of the swale during early wet season storms.

Artificial wetlands are constructed as shallow ponds (approximately 0.5 to 0.75 m deep) with impermeable liners on the bottom. The ponds are planted with a variety of aquatic plants. Stormwater enters via a sediment basin (to allow sediment to be removed by sinking to the bottom). Water then slowly passes though the pond where its soluble pollutants and particulates are removed through adsorption, absorption, sinking or biotransformation. It is estimated that effective treatment requires a pond to treat at least 90% (there is an estimate of 80% for Darwin) of a catchment's stormwater flow. It is estimated that this can be achieved using a 72 hour retention time in the pond, and a pond area equivalent to 6% of the catchment area. The system would lose plants during the Dry season and potentially suffer diminished performance during the early Wet Season. There have been unproven suggestions that this might be remedied using irrigation in the Dry season, or by maintaining deeper areas in the pond. All systems have a bypass from the sediment basin to cope with high flow rates.

Recent subdivision developments in Darwin and Palmerston have adopted some of these measures for stormwater treatment. The effectiveness of these systems remains to be determined and the implication for mosquito habitat needs to be further investigated

3.4.2. Effectiveness of Stormwater Treatment Methods

Stormwater treatment systems are designed to achieve particular efficiencies using hydrological calculations. A program called MUSIC is usually used in Australia to determine system design parameters. Results of the model are used by local authorities to set standards of performance and design.

The NT EPA is unaware of any systematic field data on the performance of the systems in tropical conditions. The only partially relevant data come from a study conducted on systems on the Gold Coast, Queensland.

A large number of systems were inspected before a final selection was made for the Gold Coast study. This was done to ensure that the systems studied were in working order. The study found that:

- "there is a disjuncture between the engineering design and the ability of the construction industry to build systems to their design specification";
- "once systems are constructed they are poorly maintained and very rarely monitored";
- "many systems that are poorly maintained are likely to be ineffective from a hydrologic and/or water quality function";
- "most systems were designed as wetlands at the end of a development";
- "most wetland systems found had turned to ponds as outlet structures had blocked, leading to rising water levels and the demise of vegetation."

There is clearly no point in designing and building expensive structures that do not conform to design standard, and are not maintained. These factors seem the dominant influence in determining the effectiveness of stormwater treatment in south-eastern Queensland; to the extent that there was no point in undertaking a study on the effectiveness of most systems.

The results of the study provide insights into differences between designed for and realised outcomes of stormwater treatment, and factors that influence the level of success achieved.

The systems studied were designed using water quality parameters recommended by South East Queensland standards. The systems were designed for inflow water quality parameters twice as high as the pollutant concentrations of stormwater runoff recorded during the study. This is compounded by system designs that did not account for the usually observed high level of variability in the pollutant concentrations of stormwater. These factors indicate that modelled outputs may not provide a sound indicator of the water quality results achieved by existing designs. There is a need for better designs, and a need for field monitoring of the performance of treatment structures.

3.4.3. Hydraulic Performance

The study found that the systems studied reduced rates of stormwater flow. Flow rates analysed were those that did not result in flows through the bypass system i.e. small storm events in keeping with the design specifications. The bioretention system and the wetland reduced the recorded flow rates by 94% and 99% respectively. Flow rates through the grassy swale were reduced by 50%.

The bioretention system was able to retain flows from small 1 to 6 mm rainfalls. The swale retained water from storms up to 3 mm while the wetlands overflowed in all events. These rainfall events are well below wet season events in Darwin.

Stormwater volumes from rainfall that did not result in overflow from the bioretention system were reduced by 42%, with modelling indicating that the system could reduce the volume of flow from all storms by 24% over 23 years. The swale reduced the volume of flow by 25%, and the wetland had no appreciable impact on flow volume.

The study concluded that the systems could significantly reduce peak flows although the high proportion of stormwater flows bypassing the system was a concern and indicated that the systems were undersized.

3.4.4. Water Quality Performance

The stormwater treatment systems provided for significant reductions in the pollutant concentrations of stormwater that passed through the systems (i.e. not including flows through the bypass). Suspended solids and nutrients removed by the systems would require periodic removal and disposal. Results are provided in Table 3 below.

The bioretention system did a relatively poor job of removing soluble nitrogen and phosphorous as NO_x and PO_4^{3-} respectively (less than 20%). The wetland was more efficient in removing these pollutants (90%).

Removal of metals varied according to treatment system and according to different metals. The bioretention

Treatment System	Total Suspended Solids (%)	Total Nitrogen (%)	Total Phosphorous (%)	Metals (%)
Swale	82	47	52	-
Bioretention	72	42	49	32-80
Wetland	83	50	50	66-80

/ **Table 3: Percentage reduction in pollutants in each of the stormwater treatment systems** system removed 80% of lead and zinc, and 32% and 56% of aluminium and copper respectively. Stormwater from the swale had low metal concentrations other than for zinc.

Although the systems functioned well in removing pollutants from water treated, some outflow concentrations were high with respect to the ANZECC (2000) guidelines. For example both NO_x and PO_4^{3-} increased in concentration in the outflow of the bioretention system (up to 40 times the ANZECC trigger values).

The stormwater systems functioned well by removing significant amounts of pollutants from stormwater that was actually treated. This was in agreement with South Eastern Queensland's guidelines for stormwater quality. The major contributors to these reductions were:

- reduction in outflow volume from the bioretention system; and
- a reduction in the concentration of pollutants in outflows from the wetland system.

The greatest limitation on the effectiveness of the systems was the failure to treat 90% of the stormwater. This would be even more significant under Darwin's rainfall regime.

The small size of the systems was the primary cause of the limited proportion of water being treated. The bioretention system occupied 3.8% of the catchment area, twice the size of that recommended in the South East Queensland guidelines. The wetland (1.8% of the catchment) exhibited overflow in all rainfall events and was clearly too small.

Achieving a desired treatment of 90% of stormwater flows (a recommendation for Darwin was 80%) would require a radical review of the required hydraulic capacity of proposed systems. This does not diminish the importance of examining and assessing the most appropriate plantings for bioretention and wetland systems, different media for bioretention basins, or possible structural variants of these systems. It only means that achieving the water quality aims of treatment is largely dependent on improving the hydraulic capacities of systems.

There are sound economic reasons for why stormwater treatment systems are often too small. Adequately sized system versions of current designs have the potential to occupy large proportions of new urban developments, reducing the area of land available for housing and greatly increasing the cost of individual blocks. This impediment is compounded by local authorities' understandable concern about taking on a significant additional maintenance burden. Further research is required to identify systems that will be effective in the Darwin wet season.

Cost effective solutions to treatment of stormwater would provide a significant benefit to management of the inevitable future increases in pollution from growing stormwater inputs to the harbour.

4.
CONCLUSIONS ON STORMWATER MANAGEMENT FOR DARWIN HARBOUR

Information on the water quality of Darwin Harbour, the types of pollutant input occurring, and likely future pollution inputs resulting from inevitable growth in population and industry indicate that:

- water quality in the harbour remains very good in general, albeit with pockets of elevated nutrients in some less well flushed areas.
- future urban and industrial growth will inevitably lead to increasing levels of pollutant input to the harbour.
- major pollutant sources include licenced sewage and industrial discharges from licensed outfalls and stormwater.
- pollution of stormwater from diffuse sources is inherently difficult to manage and regulate.
- there are deficiencies in stormwater management and regulation.

Major steps towards maintenance of the harbour's water quality have been made through the DLRM's active research and monitoring programs (water quality, bioindicators) for the harbour, and the Darwin Harbour Water Quality Protection Plan. These activities provided us with much of the information used in developing this Strategy, and will continue to provide information on the state of the harbour, and actions to remedy deficiencies. This includes actions to improve catchment management around the harbour, and protect our waterways and riparian ecosystems. These activities do not require replication in this Strategy.

A successful Strategy needs to focus on managing the input of stormwater pollutants to the harbour. This can only be achieved in two ways: manage pollutant inputs at the source; or remove the pollutants from stormwater prior to release into the harbour. Each of these requires remediation of regulatory inadequacies, and effective tools to reduce potential for pollution or treat stormwater. Each of these activities must

/ Deployment of oil response kit to contain oil in drain involve gaining community, industry and local authority awareness, support and involvement.

Management of input of pollutants to stormwater systems offers short term benefits in reducing pollutant loads. Some management occurs with the use of gross pollutant traps, sediment traps, and street sweeping. There are recent cases in the Darwin Harbour Region of urban subdivisions adopting forms of stormwater treatment. These ongoing mechanisms need support from reductions in point source pollution, avoidance of disposal of wastes to stormwater, reduction in pollutants from diffuse sources and elimination of illegal dumping of wastes. These actions are poorly supported by the existing regulatory framework, or are not supported at all. Establishing an appropriate regulatory framework is essential, and needs to be supported with tools appropriate for its implementation (e.g. geographic information system mapping and databases of stormwater systems and potential sources of pollutants).

Programs that provide industry and the community with opportunities to participate in reducing the growing pollutant load are fundamental to altering behaviours that contribute to point source and diffuse pollution. This could be in the form of formalisation and regulatory adoption of industry specific guidelines for pollutant management, collaborative development of guidelines and fact sheets with industry and the community, and programs to actively promote and disseminate this information.

Methods for the cost effective treatment of pollutants in stormwater are in their infancy. Stormwater treatment does not appear to provide an effective, short term solution to the need to manage the input of pollutants to Darwin Harbour. From the limited data available, existing treatment systems in sub-tropical Australia are usually undersized, poorly designed, poorly constructed and once constructed are generally inadequately maintained. These failings are essentially those engendered by economic constraints, resulting in the building and poor maintenance of systems that are less effective than intended.

Further development of these systems is highly desirable. In doing so it is critical that basic hydraulic considerations are met, and the special circumstances of Darwin's environment are carefully considered. These include: depriving mosquitos of breeding habitat; a combination of short, high intensity storms; lengthy periods of storms and, showers during monsoonal events; long Dry seasons; and waterlogged soils in the wet season. Issues of maintenance and system sustainability need to be a focus of design development and planning.

5. FURTHER READING

Alderson, A. (2006). The Collection and Discharge of Stormwater from Road Infrastructure. Australian Research Report 368.

ARMCANZ and ANZECC (2000). Australian Guidelines for Urban Stormwater Management - National Water Quality Management Strategy. Australian and New Zealand Environment Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra. Australian Government (2014).

Austroads (2003).Guidelines for Treatment of Stormwater Runoff from the Road Infrastructure AP-R232-03.

Butler E.C.V., Streten-Joyce C., Tsang J.J., Williams D.K., Alongi D.M., Furnas M.J. and McKinnon A.D. (2013). A procedure for evaluating the nutrient assimilative capacity of Darwin Harbour. Report for Aquatic Health Unit, Northern Territory Department of Land Resource Management. Australian Institute of Marine Science, Darwin NT.

CSIRO Publishing (2006). Urban Stormwater: Best Practice Environmental Management Guidelines.

Darwin Harbour Beach Water Quality Task Force. (2012). Sources ad pathways of bacteria affecting water quality of Darwin Harbour beaches and Pathways. Northern Territory Government, Darwin.

Darwin Beaches water quality: http://health.nt.gov.au/Environmental_Health/Beach_Water_Quality/index.aspx#beach_water_quality

Darwin Harbour Water Quality Protection Plan web site: http://www.lrm.nt.gov.au

Darwin Harbour Region Report Cards, 2009 to 2012: http://www.lrm.nt.gov.au/water/aquatic/reportcards

Darwin Harbour publications: http://www.lrm.nt.gov.au/water/dhac/publications

Department of Land Resource Management publications: http://www.lrm.nt.gov.au/water/aquatic/publications

Greiner R., Stanley O. and Speering G. (2012). The potential role of market-based instruments in safeguarding the water quality in Darwin Harbour. Report to the Northern Territory Department of Natural Resources, Environment, The Arts and Sport. Charles Darwin University, Darwin NT.

Darwin Harbour Advisory Committee (2003). Darwin Harbour Regional Plan of Management. Department of Infrastructure, Planning and Environment, Darwin NT.

Darwin Harbour Advisory Committee (2010). Darwin Harbour Strategy. Darwin NT.

Darwin Harbour Beach Water Quality Task Force (Final Report) (2012). Sources and pathways of bacteria affecting water quality on Darwin Harbour beaches and waterways. Darwin NT.

Department of Environment (WA) (2004). Stormwater Management Manual for Western Australia.

Department of Environment and Resource Management (DERM) Queensland (2010). Urban Stormwater Quality Planning Guidelines.

Department of Natural Resources, Environment and the Arts (2008). Erosion and Sediment Control Guidelines, Built Environment, Northern Territory Government.

Department of Natural Resources, Environment and the Arts (2008). Erosion and Sediment Control Guidelines, Service Corridors, Northern Territory Government.

Department of Natural Resources, Environment and the Arts (2008). Erosion and Sediment Control Guidelines, Transport Corridors, Northern Territory Government.

Department of Natural Resources, Environment, The Arts and Sport (2010). Darwin Harbour Region Water Quality Objectives.

Department of Natural Resources, Environment, The Arts and Sport (2010). Land Clearing Guidelines, Department of Natural Resources, Environment, The Arts and Sport, Darwin. Northern Territory.

Department of Natural Resources, Environment, The Arts and Sport (2010). Pictorial Report: Darwin Harbour Potential Point Source and Non-point source pollutants.

Department of Primary Industries, Parks, Water and Environment (2010). State Stormwater Strategy. EPA Division (DPIPWE).

Department of Water (SA) (2005). Urban Stormwater Management Policy.

Dostine, P. and Townsend, S. (2012). Integrated Monitoring and Research Program for Darwin Harbour: Report to the Interim Management Committee, April 2012. (Report prepared by the Project Design Team for IRMP). DLRM, Darwin NT.

Ecologically Sustainable Development Steering Committee (1992). National Strategy for Ecologically Sustainable Development, endorsed by the Council of Australian Governments, December 1992.

EDAW (2007). Water Sensitive Urban Design Objectives for Darwin – Discussion Paper (for the Northern Territory Department of Planning and Infrastructure).

EDAW (2007). Water Sensitive Urban Design Strategy for Bellamack - (for the Northern Territory Department of Planning and Infrastructure).

IECA (2008). Best practice erosion and sediment control.

National Water Initiative Joint Steering Committee (2009). Evaluating Options for Water Sensitive Urban Design – A National Guide.

NSW Government (2013). http://www.environment.nsw.gov.au/stormwater/publications.htm

http://www.environment.nsw.gov.au/stormwater/index.htm

Parker, N. 2010. Assessing the effectiveness of water sensitive urban design in southeast Queensland. M.Sc. Thesis, Faculty of Built Environment and Engineering, Queensland University of Technology.

Queensland Urban Drainage Manual Volume 1 Second Edition (2007).

Queensland Government (2009). State Planning Policy Guideline for Healthy Waters.

http://www.collinsdictionary.com/dictionary/english/urbanization

Rapid Creek Management Plan: http://www.rapidcreek.org.au/Rapid_Creek_Landcare_Group/Documents.html

Skinner L., Townsend S. and Fortune J. (2009). The Impact of Urban Land-use on Total Pollutant Loads Entering Darwin Harbour. Report 06/2008D. Aquatic Health Unit, Department of Natural Resources, Environment, The Arts and Sport, Darwin NT.

Water Monitoring Branch (2005). The health of the aquatic environment in the Darwin Harbour Region. Report 5/2005D. Department of Natural Resources, Environment and The Arts, Darwin NT.

Waugh, P.S and Padovan, A.V. (2004). Review of Pesticide Monitoring, Use and Risk to Water Resources in the Darwin Region. Report No. 02/2004D. January 2004. Natural Resource Management Division, Department of Infrastructure, Planning and Environment, Darwin NT.

Northern Territory Environment Protection Authority
GPO Box 3675
Darwin
Northern Territory 0801