Municipal Engineering Foundation, Victoria
2010 Study Tour to USA, Canada and United Kingdom

Theme: stormwater management

San Francisco City Lombard Street


Study Team from left to right Paula Gardner, Philip Jeffry, Michael J. McGlynn (Mayor, Medford city, not in the tour team) Warren Roberts Raj Mahar, Senavi Abeykoon, , , Marcus Vanenk

Innovation in Managing Urban Stormwater Drainage Network

S B Abeykoon (BSc Eng, M Eng)
Manager, Assets
South Gippsland Shire Council

Sponsored by the Municipal Engineering Foundation of Victoria and Strathbogie Shire Council

Table of Contents

Table of Figures

List of Tables

1. Synopsis

In December 2003 and January 2004, Melbourne was subjected to heavy rain and widespread flash flooding, with consequential substantial disruption of services in some parts of the city and damage to property. Similar events were repeated few years later in Melbourne and elsewhere in the Country. 250 houses were affected over few days in North West of Victoria in January 2011 due to flash flooding. If not for the long drought period we experienced during last 17 years, the situation would have been worst. As a result, the Auditor General of Victoria investigated the current flood risk management activities of six metropolitan local government councils in Melbourne in 2005.

The findings of this investigation indicated that none of the Councils has a formal decision making process in place to identify and prioritise drainage maintenance, renewal and improvement works, (Auditor General Victoria, 2005)

This report also identified a number of challenges in managing flood risk:

- Increasing high-density development has reduced the area of porous surfaces that soak up stormwater, as well as reducing the number of above-ground drainage paths for the passage of stormwater into the drainage system
- Urban development occurring without the knowledge of location of flood risk areas
- Flood mitigation work such as increasing the drainage capacity or constructing retarding basins is usually too difficult and expensive because of the existing pattern of urban development

The Infrastructure Report Card (Engineers Australia, 2005) has been developed to provide a resource, focused on key infrastructure assets within Australia. In this report, key infrastructure assets were assessed and rated from A (very good), to F (inadequate). The report indicates a marginal improvement in stormwater assets rated D in 2002 to C_ in 2005. However the local government councils appear to have a limited knowledge of their stormwater assets. The increasing demand for network upgrades and the aging of assets have created a need for improved strategic planning in the management of these assets. Today, engineers and scientists struggle to find solutions to pressing issues such as determination of the useful life of infrastructure assets, the long term future maintenance, the renewal needs of the drainage networks, the appropriate maintenance treatment, and the treatment technique for a particular component of the network, the optimum time to effect the maintenance treatment, and the level of service.

Considering the above facts, the Municipal Engineering Foundation of Victoria offered a study award for local government engineers to participate on a study tour with the theme, "Stormwater and waste management, impact of climate change on infrastructure and the planning and delivery of public works are important community issues" and gave priority to nominations that addressed these important topics.

This report is prepared based on the information gathered on stormwater management through discussions with officers in those councils visited and papers presented in APWA 2010 annual conference in Boston. The report focuses on the innovation, strategies, processes and practices put-in place for stormwater management by those councils, visited during the tour. The report also highlights on possible applications that Local Government Councils in Victoria may implement for better management of stormwater networks.

2. Introduction

Major regional flooding occurs somewhere in Victoria about every 10-20 years and has occurred in 1909, 1916, 1917, 1934, 1956, 1974, 1990, 1993, 2005 and 2011. Localised flooding occurred in 2003, 2004, 2006 and 2011. All these events caused significant damage to private property and public infrastructure as well as significant disruption and stress to the community. National annual average damage (AAD) for flooding is $314 million. With increasing urban consolidation and possible climate changes associated with global warming, we are facing a significant flood and drainage management challenges.


Coburg, February 2006

There are three major steps in flood management, prevention, response and recovery. Prevention activities consist of planning, legislation, regulation, land use controls, enforcement and structural works.

2.1. Legislative background

At regional level Water Act 1989 and Catchment Management Act deals with flood management. At local government level, the relevant legislation includes Planning and Environment Act 1987, the Local Government Act 1989, the Building Act 1993 and the Emergency Management Act 1986. Various roles and responsibilities for authorities are stipulated in these regulations.

In relation to flood management, local councils are expected to:

- administer and enforce planning provisions and building regulations in relation to building and development on flood prone land
- provide for the conservation of natural resources and areas of environmental significance
- develop flood sub-plans as part of their municipal emergency management plans and participate in risk reduction activities
- provide the public with access to flood information
- manage local level emergency recovery support, clean-up and maintenance of core business
- implement and maintain local flood warning systems
- provide and manage local drainage infrastructure for catchment areas less than 60 hectares
- support community education and awareness

2.2. Current issues

The process for better management of drainage networks is as follows:

- Collect physical characteristics of network components such as pipes, pits, and other associated drainage infrastructure.
- Assess the drainage network component conditions
- Develop deterioration curves for pipes and pits
- Identify deficiencies in the network through capacity modelling, incorporating provisions for global warming and future development.

- Identify future maintenance, renewal and upgrade needs of the network and group into projects
- Develop a process for prioritising the projects
- Develop a sustainable funding model
- Prioritise the project to suit the level of funds available
- Execute the projects

Existing buried stormwater drainage pipes are replaced today when they become under capacity or when they deteriorate beyond their performance levels. Two types of deterioration exist in stormwater drainage pipes, namely structural deterioration and serviceability deterioration. Assessing pipe condition of every pipe in a stormwater drainage system using closed circuit television (CCTV) units is very expensive and beyond the current budget allocations of most local government councils. Developing deterioration curves needs more research work. Currently most of the Victorian councils use aged based deterioration curves established through empirical data. These curves do not represent true status of the future conditions of the network. Maintenance, renewal and upgrade needs are identified on reactive basis rather than proactively. Projects are developed on ad hoc basis and no systematic processes available for project prioritisation.

This report mainly concentrates on local drainage infrastructure, attempting to address those issues, through discussion with officers of the Councils visited and the literature presented to the APWA 2010 annual conference in Boston. I have personally visited Eastern Michigan University in USA and University College of London (UCL) to meet and discuss above issues with Professor Yichun Xie and Professor Michael Batty as part of this tour. The information gathered were analysed and recommendations made in this report on alternative ways for improving the current stormwater management practices used here in Victoria.

3. Study Tour

The team visited seven Local Government Councils and 2010 APWA national conference in Boston during the tour. The Councils were selected based on the relevant information for the topics chosen by each team member and included:

- San Francisco, Napa and Medford City Councils in USA,
- Toronto and Waterloo City Councils in Canada,
- Cambridgeshire and Leicestershire in UK.

APWA 2010 annual conference provided valuable information and knowledge for the team on their respective themes. There were 7 papers presented on stormwater related topics out of 133 sessions. The stormwater summit on the last day of the congress provided valuable information on my topic.

In addition to these visits, I separated from the group to visit two universities to meet professors who had published research papers on urbanisation, which has a major effect on future impervious areas in stormwater catchments. Professor Michael Batty from the UCL Centre for Advanced Spatial Analysis, London has been engaged for many years on research work on urbanisation and published many research papers. Professor Yichun Xie from Eastern Michigan University in USA has developed a computer model to predict future urbanisation of new developments on macro level.

3.1. San Francisco City Council

San Francisco is one of the largest cities in the world with a population around 800,000 covering an area of 231 sq. Miles.

Figure 1- San Francisco City

The governing body of the city for stormwater management is Waste Water Enterprise (WWE), a division of San Francisco Public Utilities Commission (SFPUC). The service is provided to WWE by Bureau of Engineering, an in-house consultancy service. Construction management is done by Bureau of Construction Management (BCM) and maintenance and small repairs are done by Bureau of Street and Sewer Repairs (BSSR).

Wastewater collection system covers an area of 49 sq.miles and serves day time population of 1 million. All major new developments are separated from this combined system and are what is called Municipal Separate Sewer Systems (MS4). The MS4s are governed by National Pollutant Discharge Elimination system (NPDES) of the United States EPA

The combined system consists of 900mile of pipes, 24,800 manholes, 22 small lift stations, 3 major lift stations and 3 plants.

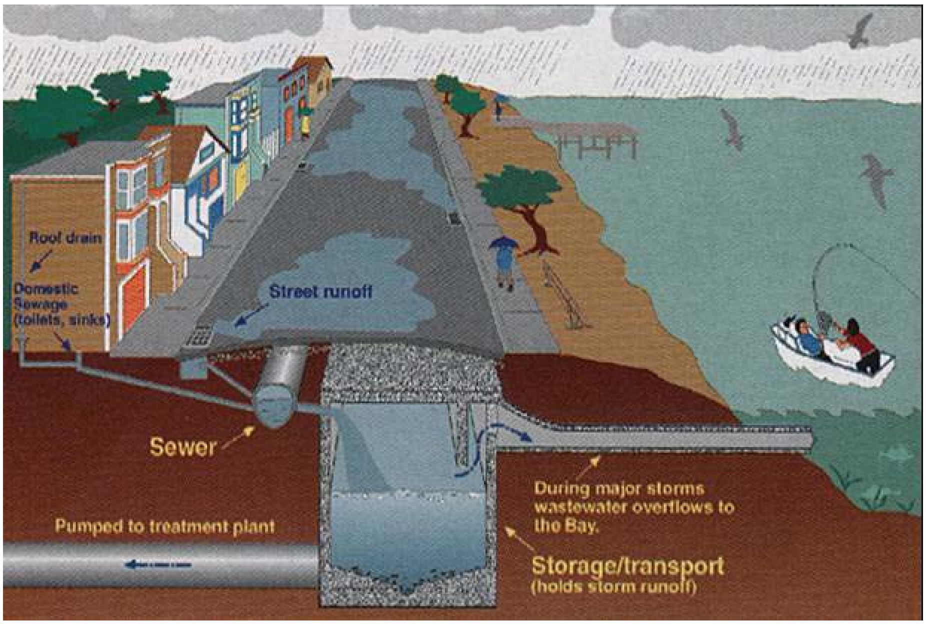


Figure 2-Typical Steet waste water infrastructure

Figure 2 indicates a typical street combine waste water infrastructure system. The storage/transport pipes are generally very large, typically 10 to 12 feet in diameter. Fig 3 and 4 indicates inside view of these pipes.

Figure 3-Repairing a defect inside a sewer pipe

Figure 4-Inside view of wastewater storage/transport pipe

The pipe network layout is shown in fig. 5. Fig 6 indicates the pipe age. Some of the pipes are as old as 145 years.

Currently the inspection and maintenance is instigated by complaints, road paving projects and other major projects. Defects are identified from the inspections and maintenance, renewal and replacement projects are developed. Condition is assessed either through CCTV camera or in the case of large sewers, walking through the tunnels. Condition score is based on Pipe line assessment program (PACP) developed by National Association of Sewer Services Companies (NASSCO) No models are used for assessing future pipe condition or deterioration. Pipes are replaced when they become under capacity or deteriorated beyond the intervention level.

Identified projects are prioritised using a risk model based on likelihood of failure, Consequence of failure, hydraulic capacity, and system risk. Details are given in table 1.

Among other things, Sea level rise (SLR) is one of the critical problems San Francisco is facing today. The Council is considering introducing back flow devices, pumping out, redirecting flows to pressurised outfalls, increasing treatment rates, constructing levees and dams to address this issue.

Figure 5-San Francisco combine waste water network layout

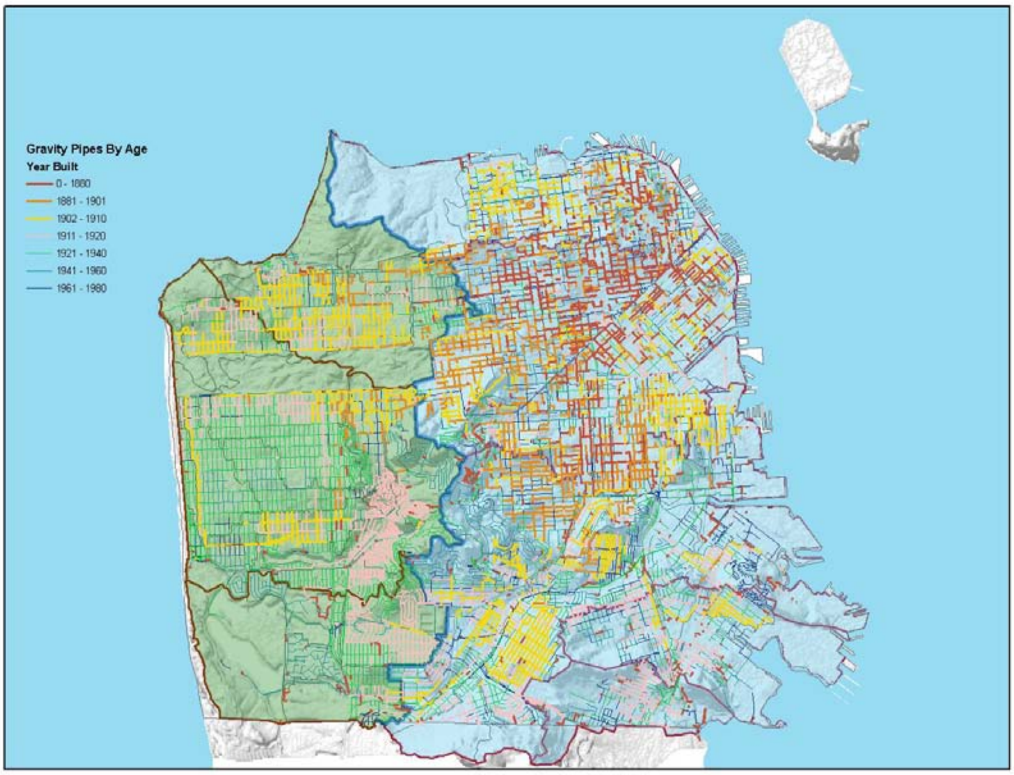


Figure 6-distribution of pipe network with age

Table 1-Prioritisation of renewal and replacement program

CSAMP Asset Failure Consequence Matrix

LAMP Example Level of Service Categories	Goal: The result to be achieved	Negligible = 1	Low =4	Moderate = 7	Severe = 10
Protect the public	• Protect public from exposure to pathogens and toxins	• Low likelihood of public exposure	• Low to Moderate likelihood of public exposure (near BART station, MUNI stops, etc)	• Moderate likelihood of public exposure (high foot traffic area, etc)	• Located next to public facility (school, hospital, etc.)
Protect the public	• Protect the public from exposure to pathogens and toxins	• Size Class I sewers (e.g., < 15 inches in diameter)	• Size Class II sewers (e.g., 15 to 24 inches in diameter)	• Size Class III sewers (e.g., 24 to 60 inches in diameter)	• Size Class IV sewers (e.g., > 60 inches in diameter)
Preserve and improve quality of life	• Commercial impacts or public annoyance	• Minimal to no commercial impacts or public annoyance	• Impact to cable car, MUNI, highway road approach, or neighborhood commercial district	• Impact to major arterial, primary transportation route, or major commercial district	• Impact to emergency transportation route, bridge approach roadway, or downtown core
Be cost effective	• Deliver levels of service at lowest long term cost (or competitive with other agencies)	• Under asphalt street and not under moratorium	• Under concrete street	• Opportunity to coordinate with other infrastructure projects	• Under moratorium street
Be cost effective	• Deliver levels of service at lowest long term cost	• No history of repairs	• 1 point repair per 300 feet in maintenance history	• 2 point repairs per 300 feet in maintenance history	• >=3 point repairs per 300 feet in maintenance history
Provide excellent customer service	• High level of customer satisfaction	• Can restore service in < 4 hours	• Can restore service in 4 to < 8 hours	• Can restore service in 8 to < 24 hours	• More than 24 hours to restore service
Be environmentally responsible	• Protect the environment	• Flows back to combined system	• Flows to surface water	• Flows to MS4 facility or CDS structure	• Impacts emergency drinking water supply
	• Meet regulations	• 100 percent compliance with permits and regulations	• Technical violation without an enforcement action	• Violation with potential for minor enforcement action	• Past history of violations and/or potential for enforcement action and fines

CSAMP Asset Failure System Risk Matrix

System Risk Score	1.00	1.02	1.03	1.04	1.05
Capacity/Sizing	Sufficient capacity to meet average and peak flow requirements; appropriate utilization and function	Under-utilized or oversized, causing O&M issues	Sufficient capacity but does not meet functional requirements or over-utilized	Able to meet current average capacity demands but not peak demands	Unable to meet current average capacity needs Known capacity issues in < 5-year storm or no dry weather redundancy/bypass options available
O&M Protocols	Complete, up-to-date, written/online, easily accessible	Complete, written/online, up-to-date, but not easily accessible	Written/online but not complete, not up-to-date, or not easily accessible	Written/on-line but not complete, out-of-date, or location is unknown	None

CSAMP Asset Failure Likelihood Matrix

Likelihood Category	Negligible = 1	Unlikely = 2	Possible =4	Likely = 7	Very Likely = 10
Physical Condition	NASSCO WINCAN 8 → MAXIMO Very good (Condition Grade 1)	NASSCO WINCAN 8 → MAXIMO Good (Condition Grade 2)	NASSCO WINCAN 8 → MAXIMO Fair (Condition Grade 3)	NASSCO WINCAN 8 → MAXIMO Poor (Condition Grade 4)	NASSCO WINCAN 8 → MAXIMO Very Poor (Condition Grade 5)

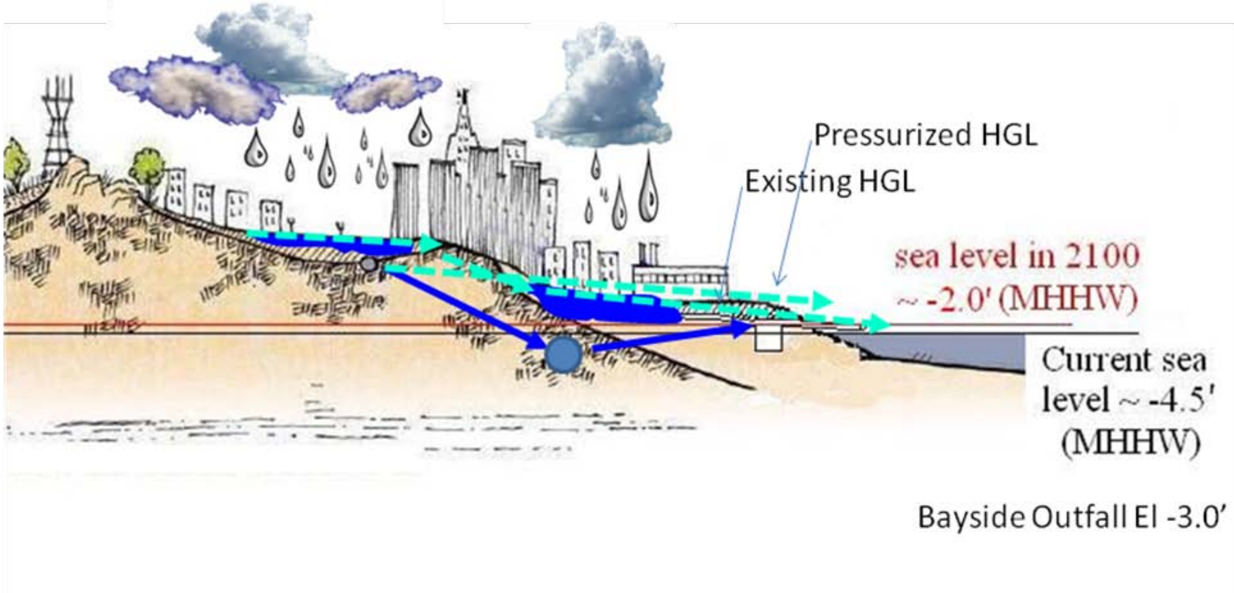


Figure 7- Approach to sea level rise

Typical example of SLR is shown in fig.7. Low impact developments (LID) are given priority as a measure of reducing outflows. Examples are shown in fig 8.

Figure 8-Examples of LID

Compared to Victoria, the approach to manage stormwater issues is outstanding and systematic in most of the areas.

3.2. Napa City Council

Figure 9 – Napa city water front

Napa city manage their drainage network in a similar manner to what our local councils does and regional water body does flood mitigation works

3.3. Toronto City Council

City of Toronto with a population of 2.5 million covers an area of 630 sq.km. The stormwater system is managed by Toronto Water, an in-house organisation responsible for portable water supply and distribution, sewer & stormwater management.

Figure 10 - Toronto City Water front

Stormwater and combined sewer network consists of 4 treatment plants, 82 pumping stations, 358 km of trunk sewers, 4,397 km of sanitary sewers, 1,301 of combined and 4,305 of storm water pipes.

Toronto's Wet Weather Flow Master Plan (WWFMP) is a long-term plan to protect the environment and sustain healthy rivers, streams and other water bodies. It's about reducing the adverse effects of wet weather flow, which is runoff generated when it rains or snows. As usual in urban environment, in Toronto, a lot of stormwater runs off roofs, roads and parking lots. It trickles down through drain pipes and empties into stormwater grates. Once it enters the grate (having collected dirt, oil, grease and a lot of other pollutants along the way), it travels through the extensive storm sewer system - 4,305 km in all - to some 2,600 outfalls or outlet pipes. In some cases, stormwater mixes with wastewater in the combined sewers or infiltrates into sanitary sewers. This causes the wastewater system and the City's sewage treatment plants to be overloaded and untreated water enters the rivers, streams and Lake Ontario, resulting degraded water quality conditions from an environmental and physical perspective.

WWFMP sets out to accomplish 13 objectives under four major categories:

- water quality
- water quantity
- natural areas
- wildlife and sewer systems

WWFMP is a long term, running through 25 years. The plan outlines programs and identified projects that, together, provide a solution for stormwater issues. A key component is raising public awareness about the issue. Raising awareness means encouraging participation by Toronto's residents in some of the community-based programs, which will help deal with stormwater pollution.

The expected achievements from WWFMP are;

- Clean waterfront beaches that are healthy for swimming
- Eliminating discharges from combined sewer overflows
- Basement flooding protection
- Protecting City infrastructure from stream erosion
- Restoring degraded local streams
- Improving stream water quality
- Reducing algae growth along the waterfronts and in streams
- Restoring aquatic habitat

The programs initiated are:

- Public education
- Source controls
- Municipal operations
- Basement flooding protection
- Conveyance controls
- Beach water quality improvements
- Protecting our waterfront
- Stream and aquatic habitat restoration
- End-of-pipe facilities
- Monitoring plan effectiveness

Most important programs from the WWFMP for stormwater network management is discussed below.

Source controls

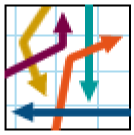
Source control measures are the first step in the hierarchical approach to managing wet weather flows by dealing with stormwater on site where it falls. These measures are carried out through programs such as:

- Mandatory Downspout Disconnection Program: This program reduces basement flooding, decreases lake and river pollution, and captures water from disconnected downspouts and then reuses it for watering gardens and grass. For combined sewer service area

- **Green Roof Incentive Pilot Program:** The overall goal of this program is to encourage green roof construction in the City. In addition, the program will benefit stormwater management by the reduction in stormwater flows.
- **Rainwater Harvesting Demonstration Project:** Rainwater harvesting not only manages the path taken by storm runoff to the lake but also diverts it to on-site non-potable uses such as irrigation and toilet flushing, thereby reducing potable water use, saving energy, operating costs and meeting WWFMP goals. Demo project will be taking place at the Automotive Building at Exhibition Place.
- **Tree Planting:** Planting trees can have multiple benefits in urban areas, including reducing the volume of stormwater runoff. While planting trees can help capture an initial portion of stormwater runoff, it can also increase evapotransporation (water expelled to the atmosphere) and infiltration.

Municipal operations

"Search and destroy" cross connections



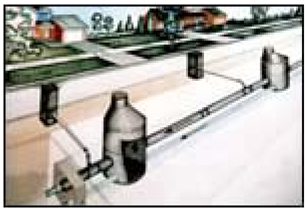
Don't let the title fool you. This is not a Steven Seagal movie. It is, however, a down-and-dirty story about cross-connections in our underground. That's because cross-connections are stormwater pipes that are connected to the sanitary system when they should be connected to the stormwater system, or vice versa. Our mission: to locate these cross-connections and fix them. It's a tough job but someone has to do it…over the next 25 years.

Basement flooding protection

Protecting homes from basement flooding is one of the City's first wet weather flow or stormwater pollution prevention projects. Over the next five years, the City is tackling those clusters or areas particularly vulnerable to basement flooding. Some of the ways we're dealing with it are by:

- replacing sewers where possible
- introducing isolation valves; these valves automatically close when the sewer backs up, stopping water from entering the basement
- reimbursing for the disconnection of weeping tiles and downspouts which contribute to basement flooding

Conveyance controls



Controlling the stormwater as it travels along the drainage system is what conveyance controls methods are all about.

Two major types of conveyance controls are the exfiltration and the filtration systems. Simply put, they refer to having "leaky" pipes that allow the stormwater to leak through and, where possible, seep into the ground. If the soil can't absorb the water then porous material, such as sand or gravel, is put around the pipes to help filter the stormwater. What isn't captured by the soil or sand re-enters the stormsewer pipes where we try to control it at end-of-the pipe.

Other conveyance controls include ditches (or swales) and sewer separation -- one of the methods we're using to handle combined sewer overflows and basement flooding.

The goal is to protect the existing ditch network or put in "leaky" storm sewers to about 25 per cent of the system.

Tanks and tunnels capture and hold combined sewer overflows and stormwaters which then are treated before returning to the lake.

- The captured flow in tunnels and tanks use ultraviolet lights to kill bacteria in the water before releasing it slowly back into the lake.
- Flow balancing captures stormwater runoff and filtrates treat it through the use of ponds and wetlands. One example of a flow balancing system is Dunker's Flow at the Scarborough Bluffs.

Using tanks and tunnels for storing sewer discharge for subsequent treatment is an effective concept that we're already using in this city. In fact, our eastern beaches have tanks and our western beaches have a storage tunnel but more is needed to protect the environment.

Areas scheduled for work in the early stage of the plan include the Eastern Beaches and the Etobicoke, Toronto (Ellis Ave.) and Scarborough waterfronts.

End-of-pipe facilities

If we're unable to remove enough stormwater when the water enters the system or transports across it, then it will be tackled at end-of-pipe. As the name suggests, this is where the stormwater pollution journey ends before it enters the lake or other water bodies.

Two types of end-of-pipe facilities exist: above ground, which involves stormwater ponds and constructed wetlands, and below ground facilities such as storage tanks and tunnels.

We've planned more than 200 end-of-pipe projects, with the bulk of them being above ground. Above ground is preferred because facilities are easier to access, maintain and are cost-effective to build. We do, however, need a lot of land to build wetlands and ponds.

Where land is at a premium, we go underground and build storage facilities or tunnels. Not as easy to get to but definitely very effective in dealing with stormwater and combined sewer overflows (CSO). The plan calls for the building of:

- 180 ponds/wetlands
- 16 CSO facilities
- 507 stormwater facilities
- 4 CSO treatment facilities are planned

Monitoring plan effectiveness

How effective is our plan? Is it meeting our expectations? Are the projects meeting their targets?

Throughout the life of the plan, we'll be looking at different measurements (depending on the projects) to answer these and other questions to know how well our plan is working.

For instance, we'll be testing beach water daily, not just during the summer months. And we'll be monitoring ponds, wetlands and shorelines against specific baselines (or references points) to see if they're performing as expected. Bottom line: we want to know if our projects are making the right kind of difference. Of course, all plans are 'living' documents that evolve. That's why monitoring also identifies projects which might need modifying throughout the 25-year period.

The total capital cost for the 25-Year Plan is approximately $1.047 billion or $42 million per year. Operational and maintenance costs to implement the capital projects is an estimated $16 million annually.

3.4. Waterloo city council

Waterloo situated about 115km south west of Toronto, has a population of 121,000. The stormwater network is managed by Water Services Department. This department is responsible the overall operation of the water distribution and wastewater collection systems, serving virtually all residents and businesses within the City of Waterloo (28,416 customers).

The urban drainage system includes the storm pipe (minor) system and overland flow along roadways (major system) and watercourses. The intent in the original designs was that the storm sewer system would convey runoff generated by a storm with a return period between 2 years and 5 years (depending on the year and standards in effect at that time). During more severe events runoff rates will either exceed the storm sewer capacity or the catch basin inlet capacity. At this point surplus flows will be conveyed along the roadways to the receiving watercourse. Where storm water

management facilities had been constructed the minor and major drainage systems would be routed through the facilities prior to release to the receiving watercourse. Table 2 indicates the extent of the stormwater network.

Table 2 – Drainage Asset Inventory Summary

Description	Quantity
Bridges	5
Culverts	276
Storm pipe Outfalls/Headwalls	350
Pipes	340km
Catch Basins/Kerb inlets	7,388
Pits (Manholes)	14,804
Ponds	63
Oil/Grit separators	33
Ditches	23km
Streams and channels	48km
Street Sweeping	690 kerb km
Leaf collection	500 kerb km
Cleaning/Sweeping Bridges/Islands	5

Waterloo Council has undertaken a Master Drainage Study (MDS) in 2005 with a scope of developing a comprehensive understanding of existing urban drainage conditions, accomplished through detailed modelling of the existing urban drainage system. A hydrologic/hydraulic model and a number of GIS applications have been used to gain a full understanding of existing conditions, identify deficiencies, assess impacts of future redevelopment and intensification, and identify the most cost-effective measures for improving the urban infrastructure and reducing the overall impacts of urbanization on the health of Creeks. The study process consisted of five phases that extends from problem identification through to detailed design, as set out by Canadian Ministry of Environment for planning and designing of municipal infrastructure projects, in order to meet the requirements of the Environmental Assessment Act. Figure 11 shows the five phases of the study. According to current design standards there will always be positive drainage up to a maximum depth of 250mm along the road system to a storm water basin or the receiving watercourse. This will ensure that the temporary flooding is confined to the road reserve and will not represent a safety hazard.

In order to understand the existing drainage conditions within the study limits in more detail, three computer simulation models (XP-STORM) have been developed to estimate storm water runoff rates, and to estimate the capacity of the storm sewer and stream network. The first model is based on the previous study to compare and validate the model. This is a macro model to provide a systematic methodology for developing a calibrated hydrologic model that would consider the entire watershed, while also providing the basis for developing a detailed micro model that could be used to assess the storm sewer system. This model only represent the status as at 1993 and include only those stormwater facilities existed prior to 1993. The second model is an upgrade of the previous model to include all the stormwater facilities currently installed. The third model is a micro model that includes the entire drainage system at network level. Micro Model can be used to assess the storm sewer system capacity and to determine the rainfall events that will cause the system to surcharge (exceed the sewer capacity). These models were calibrated using actual past rainfall events in the area.

The pipe system details and the model parameters for the detailed subcatchment areas have been generated by utilizing the City of Waterloo's Geographic Information System (GIS) database though some of the pipes and pit details were estimated. Database information such as land use zoning, topography, aerial photography, and pipe layouts have been used to define more detailed drainage areas and to define model parameters such as the percentage of impervious land (e.g. paved areas), shape and slope of the drainage areas. The database also provided storm sewer details such as pipe inverts, pipe diameter, ground elevations at manholes and outlet locations to the stream network.

Based on this study they have found that there are very few drainage problems in areas urbanized after 1970. The storm pipes have sufficient capacity and there are few overland flow problems. In contrast the drainage in pre-1970 areas is

inconsistent. Storm pipe capacity is variable and overland flow paths are generally poorly defined or occasionally non-existent.

A comprehensive watershed study has been completed for the region by Grand River Conservation Authority taking into account population growth, possible scenarios for future developments, land use changes, environmental and other constraints etc. In this study future impervious areas were assessed using the forecasted increases in dwellings based on extrapolated population statistics .City of Waterloo has identified future land use zones based on this study. These proposed land use zones were used to calculate future impervious areas for the model. Table 3 indicates the details of these impervious percentages.

Table 3- Details of Catchment Impervious Areas

Catchment area	Impervious Percentage		
	Area (ha)	Existing	Future
315	345	35	37
317	140	41	46
318	342	38	38
319	180	33	44
320	352	45	49
321	407	47	54
Total	1,766		

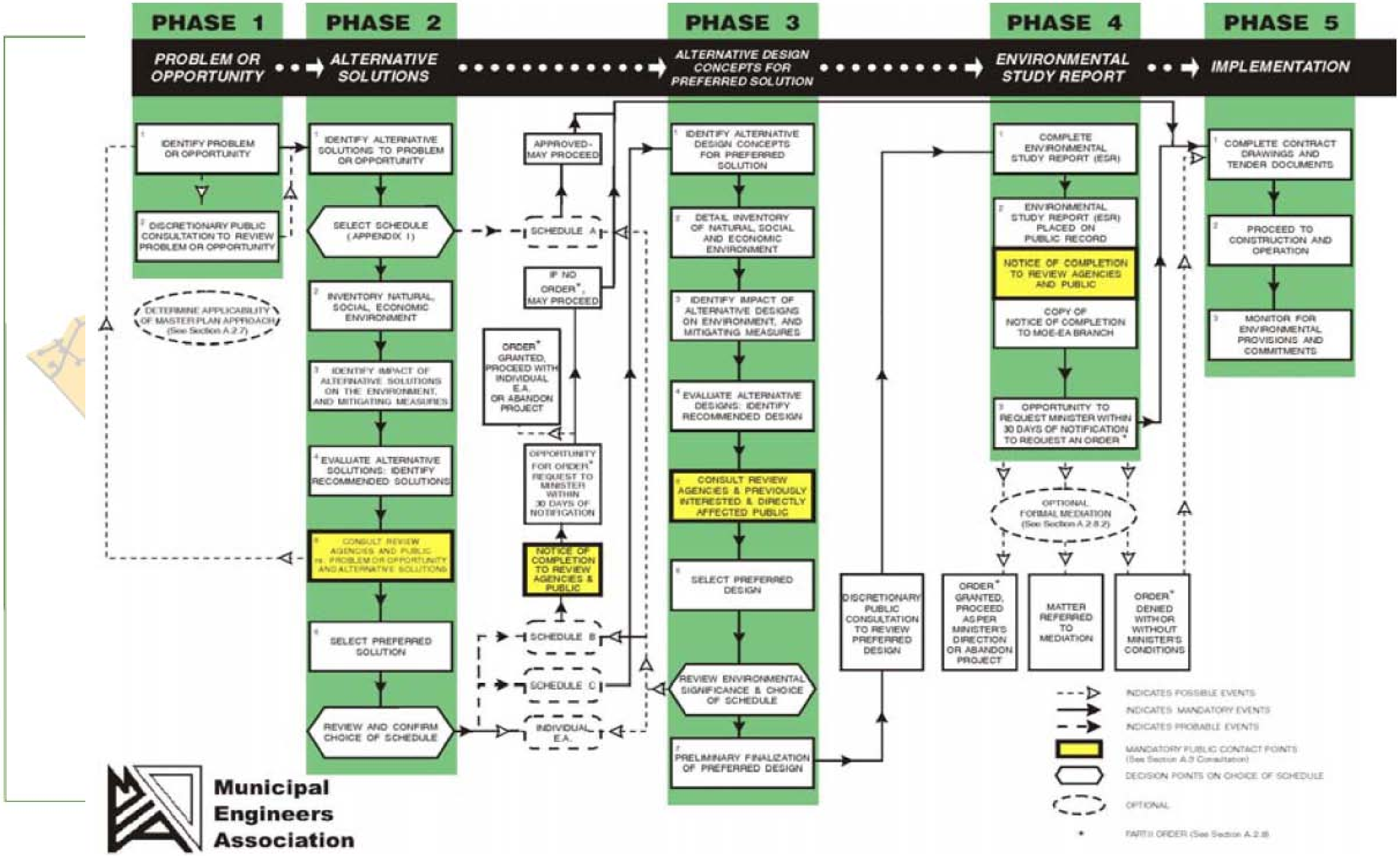


Figure 11-details of the study phases

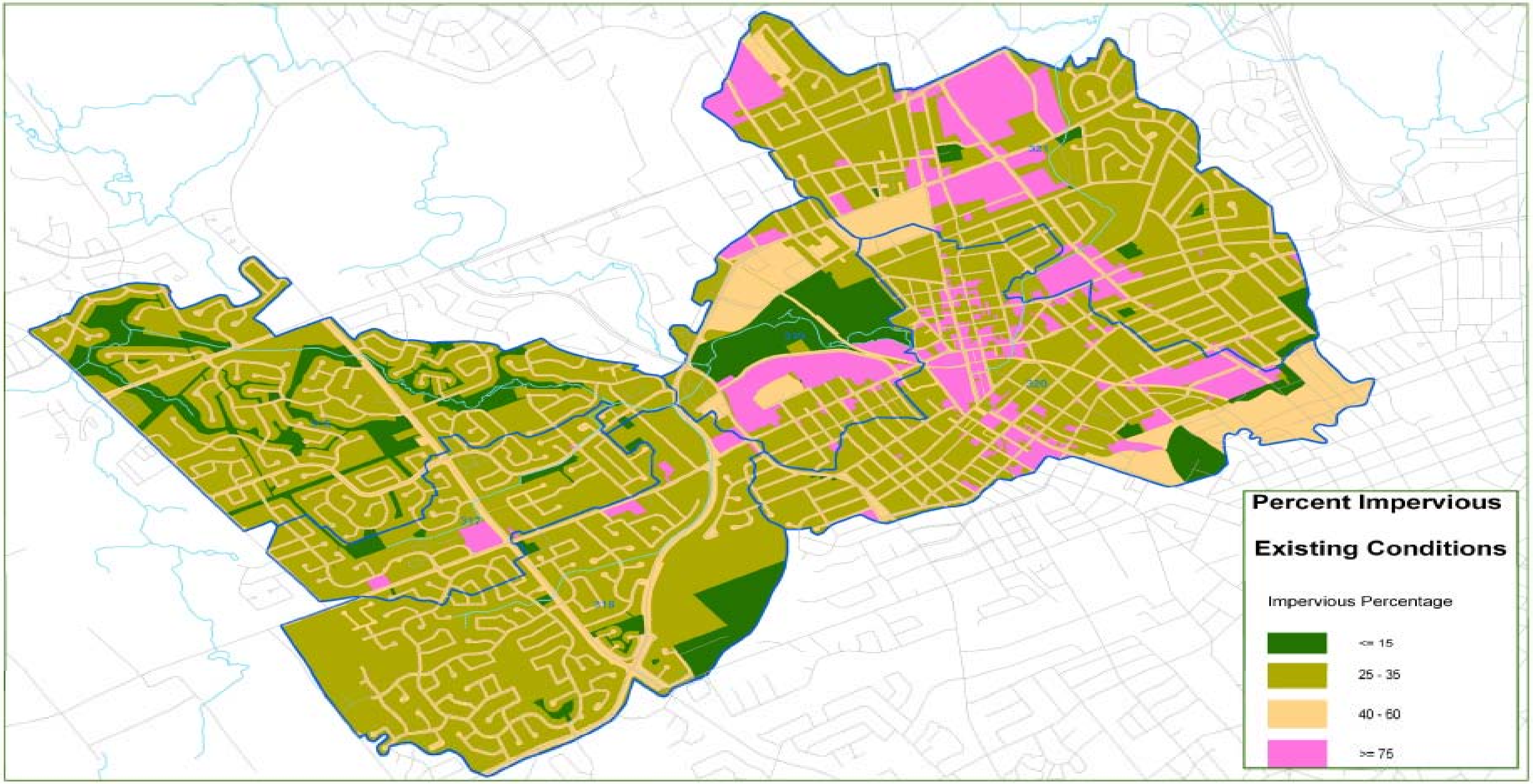


Figure 12-Percentage Impervious, Existing Condition

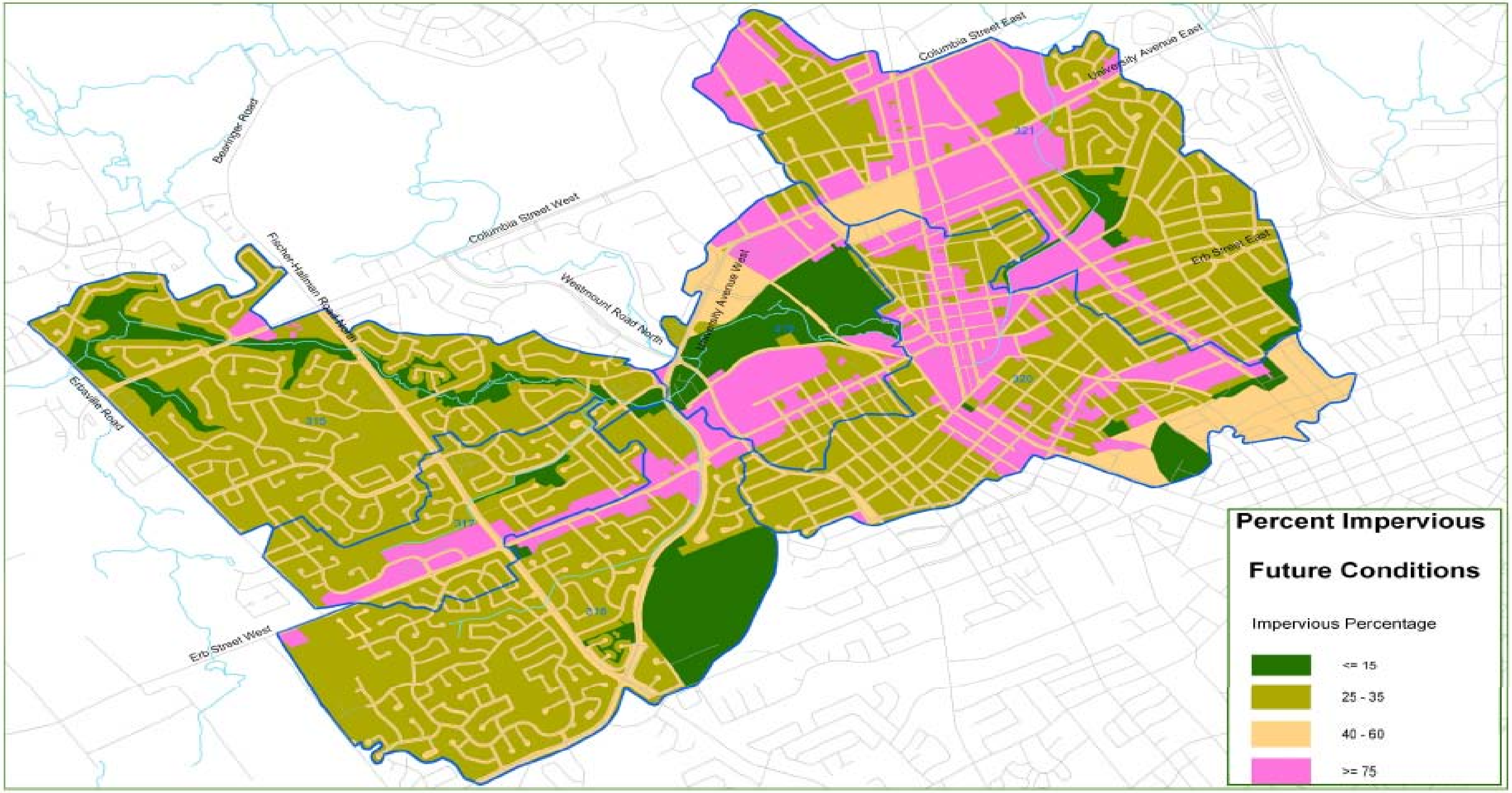


Figure 13 – Percentage Impervious, Future Conditions

The study has identified current and future network deficiencies and recommends including upgrade projects in the capital works programs. Proposals include pipe upgrades, construction of wetlands, water sensitive urban designs, green roof programs, providing erosion protection works etc. The Council has already initiated replacing the roof of the existing Council building with a green roof as a measure of the reducing runoff.

Another study has been carried out jointly by Kitchener city council and Waterloo city council to analyse the Stormwater Management Program and Funding. This study is a collaborative effort between the Cities of Kitchener and Waterloo as part of their joint services initiative that is investigating the potential for efficiencies in better service delivery to citizens in both communities. The overall study features two key components:

- An identification of the stormwater management (SWM) program needs and expenditures; and
- An evaluation of the appropriate funding mechanisms to support these needs and the implementation plan.

This study was prompted by a variety of SWM program needs for both Cities, including:

- Identification of deficiencies in the current levels of service and with respect to legislative requirements;
- Inability to fund current SWM infrastructure needs (both construction and maintenance);
- Desire to consolidate and coordinate SWM activities and services that are currently spread across multiple departments and budgets;
- Need to improve the existing level of service, better plan, schedule and proactively manage their respective SWM programs; and
- Develop an appropriate and sustainable source of funding (i.e., consistent from year to year) to support the improved SWM program and protect the existing stormwater infrastructure with funds that are dedicated solely to SWM and generated on a fair and equitable basis.

The study process includes public forums, individual discussions with key stakeholders, research focus group meetings, technical memorandums etc. The existing stormwater management program includes operation and maintenance, regulatory requirements, environmental compliance, and planning and management. The current average annual SWM program expenditure in Waterloo City Council is about $2.8 million dollars/year, representing approximately 5.7 percent of the City portion of property taxes.

A sustainable level of service represents an intermediate alternative between the current and ultimate desired service levels that ramps up services to meet the capital and O&M needs and regulatory requirements over a realistic timeframe. The sustainable service level quantifies City staff's assessment of future SWM program activities and expenditures required to:

- Provide a more proactive and preventative maintenance program;
- Provide additional activities to meet provincial and federal water quality requirements;
- Manage assets in a more sustainable manner; and
- Meet service expectations of the public.

The average anticipated stormwater expenditure for sustainable level of service in Waterloo is $4.5 million dollars/year, representing approximately 9.5 percent of the City portion of property taxes.

Funding options investigated in the study are:

- Property Tax
- Development related charges and fees and
- Stormwater rate

A stormwater rate based on impervious area was identified as the most fair, equitable and sustainable funding mechanism, where the costs are allocated based on the relative contribution of stormwater runoff and pollutant loading from all properties.

The implementation of the stormwater rate is not only a mere reallocation of municipal SWM program costs compared to current property tax based funding, but also supports the Cities' overall Environmental, Planning, and Engineering/Infrastructure goals and objectives on three key fronts. That is, the implementation of the stormwater rate offers the following key benefits:

- Achieves the shared City principles of fairness, equity and sustainability;
- Provides a flexible mechanism to support the current and future needs of the SWM program; and

- Offers financial incentives for property owners to provide on-site controls to reduce stormwater and pollutant loads to the municipal SWM system, through the adoption of a credit policy.

The key challenges of the stormwater rate include:

- Additional implementation costs. There is a common misconception that a stormwater rate entails significant implementation costs and that there is a need to reorganize the City's administrative structure to implement a stormwater rate. A critical success factor is addressing these misconceptions at an early stage in the rate study by presenting factual accounts of the anticipated administration costs. Although a stormwater rate does not generally result in organizational restructuring, it does force a change in financial reporting methods towards better cost accounting. Itemizing specific SWM labour and equipment expenditures is a good business practice and not necessarily a challenge.
- Explaining the new fee to all sectors of the public. A structured public consultation program is a critical success factor in the implementation of a stormwater rate, since a new funding mechanism may not be well received by the public. A key feature of the public consultation program in this study was the development and facilitation of a Stormwater Advisory Committee (SWAC), whose members represented different segments of the community and brought to the discussion the interests and concerns of each group. Given the typically low profile and level of understanding of the municipal SWM program by the general public, the formation of an advisory committee is a critical undertaking in a stormwater rate. Experience has shown that a successful SWAC process will address the more contentious issues of key stakeholder groups at an early stage. On the contrary, avoiding opponents during the course of the study could result in the rate being defeated during Council deliberations, depending on the tactics of a delegation of those opposed to the rate.

Compared to other councils, Waterloo seems to be well ahead on stormwater management.

3.5. City of Medford

Medford city has developed a stormwater management plan considering mainly on stormwater quality rather than the quantity as required by US regulations. The management of stormwater network is most similar to Victoria rural councils.

3.6. Cambridgeshire County Council

Cambridgeshire County Council Is a regional local body, about 100km north of London with a population of 600,000. Cambridgeshire covers Cambridge city, East Cambridgeshire, Fenland, Huntingdonshire and South Cambridgeshire. Stormwater management is a collective effort of Internal Drainage Board, Highway Agency, District Councils and Shire Councils.

Highway agency looks after the drainage on national roads and County looks after drainage on other roads. Internal drainage boards looks after the drainage in older developments.

Stormwater management is similar to what we are doing in Victoria. Inspection frequencies have been defined for each category of drainage assets such as pipes, kerbs, pits etc. and defects falling within the intervention level are rectified.

Sustainable Drainage systems are incorporated in most of the new developments. Examples are swales, pours pavements, basins etc.

3.7. Leicestershire County Council

Leicestershire does not manage their drainage network but other organisations.

3.8. Visit to Eastern Michigan University- Ypsilanti

Professor Yichun Xie has developed a computer program to predict the future developments at the fringes of existing developments based on Cellular automation process. This program can be used to predict future impervious areas in the cities where development takes place in the fringes of the city. The only disadvantage is that infill developments cannot be predicted using this program. At the moment no program has been developed to predict future impervious areas due to infill development, which is the case in most of urban cities we have here in Victoria.

4. Pipe Condition Predictive Model

A model has been developed as part of the research I am currently involved with University of Victoria to predict the future pipe conditions. This model is developed using the existing pipes conditions data collected through CCTV inspections on Glen Eira City Council's drainage network. The model is able to predict future structural and serviceability condition using pipe location, age, length, depth, slope, diameter, and the number of trees in the vicinity, using Artificial Neural Network (ANN) techniques.

ANNs can predict functions approximations, perform pattern classifications, clustering and forecasting and provides a promising approach for understanding stormwater pipe deterioration patterns (Samarasinghe 2007). ANNs works in the same way as biological networks operate. Input information is processed by a series of neurons working collectively to produce an outcome from the model. A basic ANN consists of an input layer, a hidden layer and an output layer. These layers are connected together by model parameters called connection weights (i.e. input weights and layer weights) and biases.

ANN with n inputs in its simplest form can be expressed as:

$$N(x) = \sigma\left(\sum_{j=1}^{n} w_j x_j + b\right)$$

Where N(x) is the output, σ is the transfer function, w_j denotes the weight associated with j^{th} input, and b is the weight associated with the bias input. The model parameters are adjusted in the training process to obtain reliable model output to match the training data and the output is validated using validation data set and tested on test data set. More details on neural network can be found in Samarasinghe (2007) and Demuth et al. (2002).

Pipe condition data was collected on 18km of drainage pipes, which is 3.2% of the whole network. The other related data such as soil type, number of trees in the vicinity, pipe slope, depth, diameter etc were extracted from the Council GIS system. The data set was randomly divided in to three groups, for training (60%), Validation (25%) and testing (15%). The detail procedure is beyond this paper, and not included here. Calculations are performed using MatLab computer program and model parameters are established for the model, which gives best results. The accuracy of the model is about 80% on structural condition and 77% on serviceability condition. The model can be used to predict future pipe conditions on drainage networks if the necessary variable data is available.

5. Discussion

The issues we are facing today with regard to stormwater network management in Victorian local government authorities are:

- The knowledge of existing drainage assets inventory data
- Lack of in-house technical knowhow to analyse drainage networks for capacity
- Current and predicted future asset conditions, needed to prepare maintenance programs, and renewal & upgrade projects
- Projected future planning studies not done in most of the councils and hence the need of a model to predict future urbanisation and increases in impervious areas required for network capacity analysis.
- Justifiable project prioritisation mechanism to match the existing budget
- Sustainable funding mechanism to fund the drainage network management.
- Lack of initiatives and technical knowhow in incorporating sustainable drainage systems such as swales, rain gardens, ponds etc.

Some of the local authorise we visited have addressed most of the above issues, but not yet reached to a full confident level. For instance San Francisco City Council in USA is well advance in some areas such a project prioritising and condition assessment but does not have a sustainable funding mechanism. Waterloo City Council in Canada has developed a comprehensive funding mechanism but do not have a methodology to assess asset conditions.

It is evident that various authorities manage their stormwater in ways specific to their needs and perceptions, depending on historical events that taken place in establishment of the developments. In USA the stormwater and sewer are combined and the issues they have are completely different to what we have here in Australia. The biggest problem they have is basement flooding during storms. They are now moving into separate sewer and stormwater systems.

The issues Waterloo City Council has in managing stormwater networks are similar to what we are experiencing at Victoria. Waterloo City Council is well advanced in developing a sustainable system in managing their stormwater network. They have identified the funding gap and implemented a funding mechanism to finance the gap.

Waterloo Council has gone in-depth to identify future impervious areas through the future proposed planning zones, which is acceptable. Most of the other local councils do not have their planning zones proposed or established in to the future and hence future impervious areas cannot be predicted.

Some of the lager fully developed local authorities such as San Francisco does not have this issue, as there is no room for infill development or expand the residential areas through subdivisions. San Francisco has well developed system, where they have assessed the condition of the entire network by visual inspection or through CCTV methods and identify the infrastructure shortfalls such as under capacity pipes, structural defects etc. and prepared a detailed program for upgrading and renewing the existing drainage infrastructure. They also have prioritised the projects using a risk based approach to match their current budget. The issue in their approach is that they have snapshot of the condition of the network and the renewal and upgrade projects are based on this snapshot rather than based on proactive predictive model, which will enable them to predict future asset conditions. On the other hand Victoria Councils cannot afford to carryout CCTV inspection on whole of their drainage networks due to cost constraints.

Most of our urban cities are still expanding at the fringe or through infill developments, and hence we need a model to predict future impervious area for our catchments to identify the infrastructure needs in future.

6. Recommendation

Following recommendations and be deduced based on the facts and figures presented in this report.

- Develop a comprehensive sustainable funding mechanism to manage stormwater drainage networks as all the other service providers such as Melbourne water, Telstra and power companies are currently charging. The process should be initiated at state government level through a legislative process incorporating planning departments, catchment authorities and other water corporations.
- Develop a legal process to make sustainable drainage system mandatory in new developments. This can be achieved by developing a unique infrastructure development manual to use across the board.
- Use stormwater pipe condition predictive models already developed as part of this research to predict the future pipe conditions in order to prepare maintenance, renewal programs.
- Initiate research work to develop a model to predict the increase in impervious areas within urban areas and at the fringes. The predicted impervious areas then can be incorporated in the hydrology and hydraulic models to analyse the pipe capacities and develop future upgrade programs.
- Develop a common project prioritisation procedure considering public protection, quality of life, cost, customer satisfaction, environmental factors and pipe capacity as identified by San Francisco City Council.
- Considering the amount and complexity of work involved in managing stormwater networks, it is recommend employing people with greater Technical/Engineering expertise in Local Government who are capable of performing network capacity analysis and flood modelling.
- Open new training avenues for the local government staff to be familiarise with hydrology and hydraulic modelling and sustainable drainage systems such as porous paving, swales, rain gardens, ponds etc.

<u>Reference</u>

Engineers Australia, 2005, “Infrastructure Report Card”

Department Natural Resources and Environment, 1998,”Victoria Flood Management Strategy”

Waterloo City Council, 2006, “Kitchener-Waterloo Stormwater Utility Feasibility Study”

Waterloo City Council, 2004, “Waterloo Master Drainage Study”

Samarasinghe, S. (2007). Neural Networks for Applied Sciences and Engineering, Auerbach Publications

Demuth, H., Beale, M., and Hagan, M. (2002). Neural Network Design, The MathWorks

Web Sites:

http://www.sfgov.org/
http://www.cityofnapa.org/
http://www.cambridgeshire.gov.uk/
http://www.toronto.ca/
http://www.city.waterloo.on.ca/
http://www.medford.org/Pages/index
http://www.leics.gov.uk/