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City Water Balance (CWB): an analysis of a new Integrated Urban Water Management scoping tool, using the city of Dunedin, Florida

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Abstract

City Water Balance (CWB) is a new scoping model that has been created in association with the SWITCH project, to be used as a useful tool for sustainable urban water planning. The input parameters for this model have been analysed by attempting to use the model for the current water system in the city of Dunedin, Florida. This city gives a totally different climate, geology, hydrogeology, surface waters and water management strategies to those of Birmingham, the city that was used in the initial model testing.

The work has highlighted the need for significant updates to the aquifer input files as well as the large borehole management option and waste water recycling option. Many other smaller scale model updates have also been suggested. Due to the considerable updates that were required to make the model work for Dunedin, and the time limits of this project, the city water system was not successfully modelled and different sustainable management options for the city could not be investigated fully. However, in depth knowledge of the water management in Dunedin as well as the natural water cycle has been gained and discussed in relation to the model. Future scenarios including population increase and climate change have also been created along with different management input files, which are ready for use when the model is completed.

Acknowledgements

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1 Introduction

1.1 General

With increasing global pressures such as population increase, demographic changes and climate change, there is ever more stress on the practice of urban water management. New integrated urban water management (IUWM) methods are emerging that will assist in this difficult task, taking in all factors of the urban water system and using a more holistic approach. It is of vital importance that not only should resources be managed effectively to supply the often increasing demand, but that all aspects of the water cycle should be managed sustainably. City Water Balance (CWB) is a new IUWM scoping tool that has been created in association with the SWITCH project (Section 1.3). This project sets out to analyse this new tool by using it in a different urban environment to the one used by the creator.

This has been carried out to a point however restrictions were placed on the final analysis of the model by a need for several adaptations to the model that could not be implemented in time.

1.2 Background

1.2.1 The problems faced by urban water managers

Urbanisation can cause extensive modification to local hydrology and hydrogeology. The effects can be seen in the chemistry of the surface and groundwater along with the general water fluxes of both these water cycle components. The change from pervious to impervious land surface cover will change recharge amounts and alter the recharge distribution. Recharge will also be affected by leakage from underground pipes which supply potable water and transport waste and storm water, along with direct discharged onto the land surface and infiltration from engineered surface water bodies. Groundwater abstraction can also play a

large part on the disturbance of the natural system, lowering piezometric surfaces and altering groundwater flow.

These alterations to the natural system can produce unwanted effects including: - increased flood risk (in the urban area and/or downstream), decreased well yield and the decreased potential of groundwater as a valuable resource, declining quality of ground and surface waters, salinization, ground instability and sink holes (Tellam et al., 2006).

Rapid urbanization in many developing countries in recent years has lead to a water shortage in numerous cities. Better management of the limited resources available in these areas is therefore essential for maintaining and improving health standards (WHO, 2010). Pollution of water sources is a major consideration in the developed world. In addition to these stresses, there are increasing global pressures such as population increase and climate change which may cause increasingly heavy storms or prolonged periods of drought near urban centres (Van der Steen, 2006). Efficient management of urban water is, and will increasingly be, fraught with difficulties (Van der Steen & Howe, 2009).

1.2.2 **The traditional approach to urban water management**

The old approach to urban water management was to remove wastewater and storm water from the urban area as quickly as possible (Mitchell et al., 2001). Not only is this approach highly wasteful and in many cases unsustainable, it puts enormous pressure on downstream water bodies in terms of capacity, and can also lead to the rapid spreading of contaminated water. This endangers downstream water resources and can greatly increase flood hazards.

Conventional management methods have regarded the water supply, waste water and storm water as separate entities. When planning and operating these systems there was little

reference between the three, with limited effort to collect, store or reuse waste or storm water (Mitchell and Diaper, 2005).

1.2.3 A more sustainable future

Sustainability can be defined as follows,

"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

We must therefore accept that sustainable development requires the integration of factors which effect society, economy and the environment. Sustainability will improve if urban water management causes the system to become more equitable, having less impact between generations, or become more efficient or more environmentally friendly (Speers and Mitchell, 2000). This cannot be achieved using the old methods of water management and more careful consideration of the interactions between the man made systems of water supply and waste removal, together with the interactions between the natural water systems such as groundwater and surface water flow, are required.

1.2.4 Integrated Urban Water Management (IUWM)

To tie in sustainability considerations to urban water management, IUWM is becoming more common. It is the practice of managing fresh water, storm water and waste water as links within a resource management structure (UNEP, 2010). IUWM takes a more holistic approach allowing the different water units within the urban environment to be viewed as components all lying within a single physical system (Mitchell et al., 2001). IUWM also

recognises that this physical system lies within and interacts with an organisational framework and a larger natural setting (Mitchell and Diaper, 2005).

IUWM regards the whole urban water system, down to the site scale as it recognises that the interactions are complex. Changes to one part of the system may have downstream or upstream consequences that affect cost or sustainability of the system as a whole. Therefore when planning and managing a particular aspect of an urban water system, a wide spanning view of the rest of the system must be given and the affects considered (Mitchell and Diaper, 2005). This is without a doubt a difficult task as the complex interactions of the urban water systems of one particular city could be completely unique when compared with another.

New methods are being investigated and adopted to minimise the environmental impact of cities on supply sources and receiving waters (Mitchell et al., 2001). Alternative methods of supply and waste and storm water disposal are becoming part of the solution. One central development in this new approach is the utilization of waste and storm waters for reuse. One large benefit of IUWM is the potential to increase the range of methods available for increasing sustainability of urban water management. The more options that are made available, the better tailored to a particular setting development can be (Speers and Mitchell, 2000).

1.2.5 City Water Balance - A new scoping model

City Water Balance (CWB) is a scoping model created by Ewan Last and Rae Mackay in association with the SWITCH project. It is similar to and based on the principles employed in *Aquacycle* (Mitchell et al., 2001) and *UVQ* (Mitchell and Diaper, 2005) but has several key differences that are described in this project.

1.3 The EU SWITCH project

SWITCH (Sustainable Water Management Improves Tomorrow's Cities' Health), is an action research project that was created and co-funded by the EU and a cross disciplinary team of partners in 2006. The project was created to tackle the urban water management challenges we are faced with due to increasing global pressures such as climate change and population increase. The main aim of the project is to create a paradigm shift in the way in which urban water is managed, moving towards a more integrated approach and away from ad hoc solutions (UNESCO-IHE, 2010).

The SWITCH consortium consists of 33 partners in 15 countries worldwide, including academics, water utilities, urban planners and consultants. The partners work closely with civil society through 'learning alliances'. The creation of these learning alliances has the aim of improving communication between the SWITCH researchers and society, making information more easily accessible. The process of adoption and implementation of the new ideas and methods, to real city scenarios can then be much accelerated (SWITCH, 2010).

The SWITCH project is split into 6 research themes. Theme 5, 'Urban Water Planning', aims to bring together the natural aspects of the water cycle with the man made planning aspects of water management, to create more sustainable methods. The main breakthroughs within this research theme have been the development of simulation tools created to assist stakeholder communities. Within cities these can be applied to scope future options for Integrated Urban Water Management (Last & Mackay, 2010). The tools will be available for use through the 'City Water Information System' (CWIS) platform. One of the tools created for this system is the City Water Balance (CWB) model. This scoping model allows users to simulate the total water balance for a city, including natural and man-made systems, and then go on to explore a broad range of management strategies. The strategies can be explored in response to

pressures that are already in place on the city water, or in response to future scenarios (Last & Mackay, 2010).

Although the EU SWITCH project was only a 5 year initiative and will come to a close in February 2010, the continued development, distribution and training for CWIS will be taken over by a Ipogee Ltd, a private consulting firm based in Switzerland.

1.4 CWB – An Introduction

The model has been created using VB.Net coding. It works on a daily time step and can perform over a user specified time, most useful for viewing decadal periods. It is capable of performing a water and contaminant balance for an urban system of the city scale. The outputs of water flow, water quality, energy and cost can be used as sustainability indicators to help decision makers choose sustainable water management strategies (Last, 2010a). This project will focus on the water flow sustainability indicators. It should be stressed here that the model will not give highly accurate results at the small scale, and should not be used by engineers or groundwater modellers as a tool to base detailed descriptions of features or plans on. It is a scoping model, created to show water balance at the large city scale and should hence be used as a tool for investigating different management options by decision makers.

1.4.1 Spatial Characterisation

As water demand and runoff patterns are dependent on land cover and land use, one of the essential tasks of the user is to categorise and input different types of cover of the city area. CWB accepts these spatial inputs in a hierarchical fashion.

So that rapid characterisation of land use at the small scale can be undertaken, the ‘unit block’ concept has been adopted from *Aquacycle* (Mitchell et al., 2001). These user defined

areas have a set amount of pervious and impervious space along with a defined water demand and disposal profile. An example would be a small detached house with garden. The roof area, paved area, and pervious area included would all be described within the model inputs as would aspects such as the indoor water demand and possible irrigation demand (Last & Mackay, 2010).

Areas that contain several of the same unit block are termed ‘miniclusters’ and can be used to more quickly assign land use to large areas of the city. Most areas can be estimated by using aerial photographs, road/land use maps and some ground truthing if required.

On the largest scale, CWB uses what are termed ‘subcatchments’. Again, these are user defined and should be created to divide the city into areas around the wastewater and natural drainage system. The miniclusters lie within the subcatchments but cannot cross them. The subcatchment idea was created for CWB so that flow calculations proceed in a cascading fashion allowing downstream areas to be affected by upstream areas but not vice verse. In comparison to previous models this is a major advantage as it allows the minicluster areas to be based on land use type alone, and hence leads to a much more rapid representation of the wastewater network over the city scale (Last and Mackay, 2010).

1.4.2 Water Management Options

Water management options are available within the model at the three different spatial scales. These are summarised in the table 1.

Table 1 – CWB management options	
Spatial Scale	**Water Management Option**
Unit Block	• Rain tank • Waste water recycling • Septic tanks • Porous paving • Swales • Green Roofs • Borehole use • Sub-surface grey water irrigation,
Minicluster	• Storm water harvesting • Waste water recycling • Soakaways • Porous Asphalt • Swales • Filterstrips,
Large Scale	• Ponds • Large boreholes • Waste water recycling • Storm water harvesting

Sustainable Urban Drainage Systems (SUDS) such as ponds, swales and filter strips can be used to control storm water flows, limit runoff and even remove contaminants. Storm water can also be collected from roofs using rain tanks, limiting the runoff from non-guttered areas and decreasing water demand if it is then used for irrigation. Green roofs can cause evaporation of 40% of rainfall onto a roof, again lessening storm water runoff and stresses on the storm water drainage system. Wastewater can be recycled for non-potable use, and household grey water has potential for sub-surface irrigation where it cannot come into contact with humans. Borehole abstraction can decrease the demand for imported water. The primary function of CWB is to assess the sustainability of combinations of these options within a city (Last 2010a).

1.4.3 Innovations for IUWM

As mentioned, CWB is based on previous IUWM models: - *Aquacycle* and *UVQ*. It was a SWITCH decision to use these models as a basis for the new scoping model (Last & Mackay 2007). However, although the concepts underpinning these models are similar, CWB has several key areas that are significantly different from past models. These have been developed in accordance with the aims of the SWITCH project, allowing the model to be effectively used in the learning alliance environment with participatory decision making of IUWM strategies (Last & Mackay, 2010).

The three key innovations of CWB are: -

1) Significant weight is given to the exploitation of the natural environment for sustainable water management
2) Expansion of the available water management options in the model
3) The inclusion of energy and cost indicators (Last 2010a; Last and Mackay, 2010).

1.5 CWB and the Birmingham example

CWB has been created by Ewan Last and Rae Mackay of The University of Birmingham. Last worked on the model as part of his PhD at the University of Birmingham and therefore used Birmingham has a demonstration city, as much of the data was available.

Birmingham is a large city in central England with an elevation of 90 to 350m above sea level. It has a temperate climate and a population of approximately 1 million (Office for National Statistics, 2001). In excess of 300 Ml of water is supplied to the city everyday from the Elan Valley reservoir, located in Wales (*Khatri & Vairavamoorthy*, 2009). Water supply

is managed by Severn Trent Water Limited and South Staffordshire Water, from who much of the necessary data for the model was collected (Last, 2010a).

A detailed working model of Birmingham was created, and successful calibration and validation of CWB for this city demonstrated.

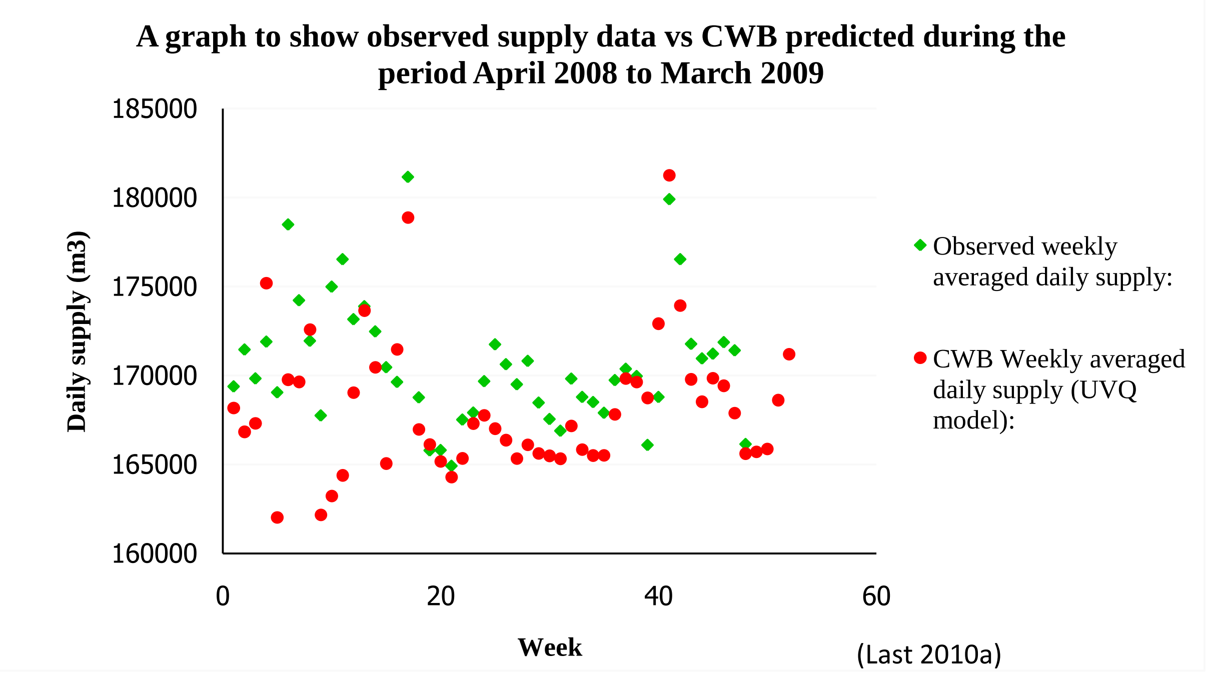
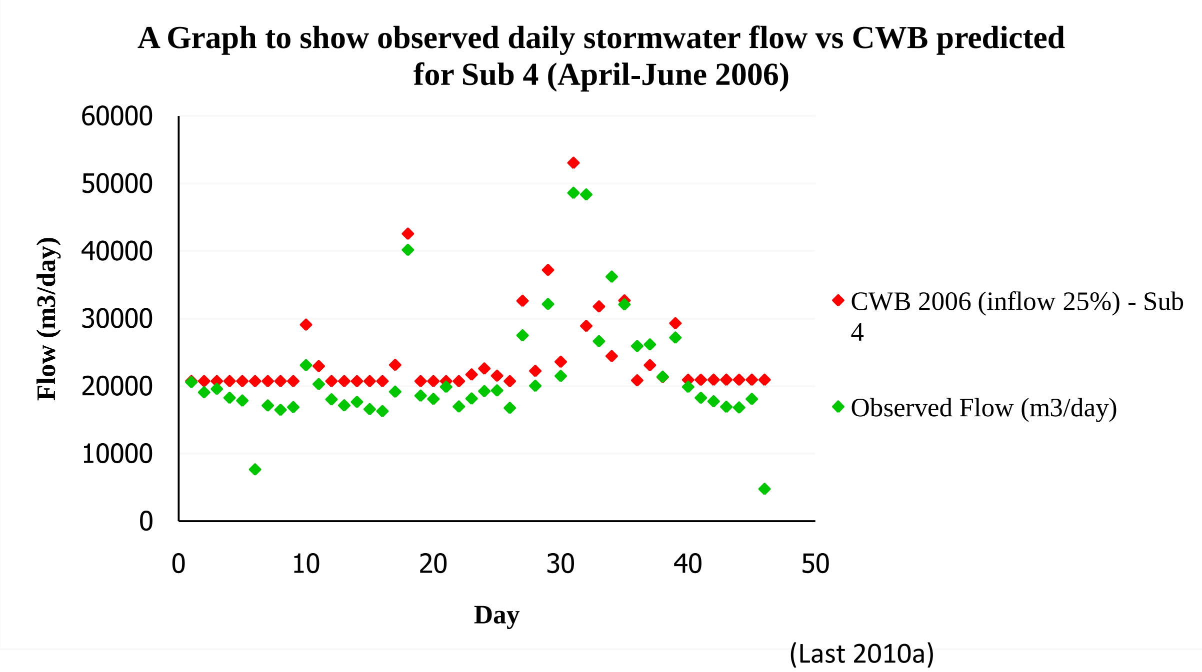


Figure 1 – Birmingham calibration

To calibrate the model past studies were used along with district meter area (DMA) records provided by Severn Trent Water Limited. Figure 1 shows the model simulation results of supply to the city area between April 2008 and March 2009, against the actually metered supply. The plot shows that the two sets of data match to a degree of accuracy that is necessary for a scoping model. The model appears to simulate both annual and seasonal variations adequately. Other data sets such as storm water and wastewater flow were also used to aid in the calibration of the model (Last, 2010a).

After successful calibration, the model was validated for the sustainability indicators mentioned.



(Last 2010a)

Figure 2 – Birmingham validation

Figure 2 shows an example of simulated storm water flow from subcatchment 4, against real flow data provided by Severn Trent. The correlation coefficient is 0.8.

Future scenarios, as agreed upon by the Birmingham Learning Alliance, were created and from here the model used to investigate different sustainable water management options for the future (Last, 2010a). The outcomes showed that medium scale rainwater harvesting along with wastewater recycling would be much more sustainable than conventional supply. Borehole use would also be more cost effective than centralised water supply but would have similar energy usage. The improvements on sustainability by using green roofs was not clear cut, but is thought to make improvements in terms of attenuation and aesthetics (Last, 2010a). Further investigation into cost and energy use was completed but will not be discussed here. Overall the study was considered a large success in demonstrating CWB's potential.

2 Project Aims

CWB has been used to model the city of Birmingham in great detail. This has been a large success showing the worth of this new scoping tool. However, to prove the worth of the model further, studies must be undertaken using CWB in different cities which will present totally different input data and problems to investigate. As Last created the model and was also the person to use Birmingham as a demonstration city, it is possible that the model itself holds many biases. The investigation of other cities using CWB should bring any other issues to our attention, so that improvements to the model can be made. The model will only be a useful tool if it can be applied to any city worldwide.

1) Hence the main aim of this project is to use CWB in a totally different city environment to Birmingham, to test how well it will work, and to improve the model code as the work continues. This will require the assistance of Rae Mackay, who has been involved in the creation of the model alongside Last.

   The city of Dunedin, Florida will be used for this purpose. It should also be mentioned here that similar work will be carried out by fellow Masters students in the cities of Accra, Ghana and Alexandria, Egypt. The three cities should offer such different climates, geology, population stresses and current water management practices amongst other model inputs, that the model will undergo thorough testing and development.

   This main aim can be split into further categories: -

   1.1 To gain a thorough understanding of the water systems and their interactions within the city of Dunedin, Florida.

   1.2 To collect and process all the necessary data for the inputs of the CWB model.

1.3 To analyse the modelling process, while using CWB. Is it well structured and easy to use?

1.4 To pinpoint areas of the model that require updating, so that all different city water systems can be modelled, and to use in depth knowledge of the city water interactions to suggest suitable improvements.

1.5 To successfully model Dunedin using CWB. (Due to the problems getting the updated model ready in time, this could not be achieved. The data which was found and processed in preparation for model calibration will however be included, so that the task of the modeller who continues this study is made simpler.)

The 2nd and 3rd aims were the original aims of the project but due to the modelling issues they had to be compromised.

2) Originally the second aim of the project was to investigate sustainable water management options for this particular city. This would have been implemented for the city under current conditions, and in response to possible future scenarios which place additional stresses on the city. However, due to the difficulties in making the necessary updates to the model in time, the model itself could not be run and the options not investigated. This project aim will be half fulfilled as the necessary ground work was completed for creating future scenarios and deciding which management options should be investigated. The necessary input files for these investigations will be created, ready for future use.
3) The third aim of the project was to investigate the sensitivity of several of the model input parameters. Again, this could not be carried out without the working model. However, ideas about which aspects of the model should be tested for sensitivity and methods will be discussed.

The energy and cost aspects of the model, along with the contaminant balance will not be investigated in this project, though they are available for use with CWB. More focus will be placed on the water balance and sustainable management strategies.

3 The Study Area

3.1 The City of Dunedin

The city of Dunedin is located in Pinellas County, near the Gulf of Mexico in west-central Florida (Figure 3). It lies at a latitude of 28.03N and has a mean elevation of 9m and hence has a sub-tropical climate. The city land area is approximately 27km^2 (City of Dunedin, 2010). To the East lies Tampa Bay and mainland Florida. To the West lies St. Joseph Sound, a narrow stretch of water that separates the mainland and Honeymoon and Caladesi Islands.

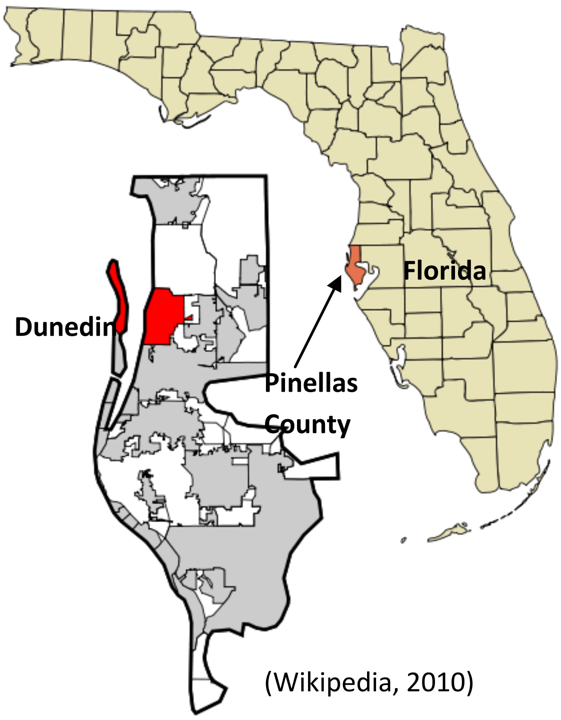


Figure 3- Dunedin location

In 2000 the population of Dunedin was 35,691 (US Census Bureau, 2000). The city now has an estimated permanent population of approximately 37,000 (City of Dunedin, 2010) and a functional population including tourists and seasonal occupants of around 44,000 (City of Dunedin, 2008). Most buildings are residential. There is a quaint downtown area that consists of small shops and eateries. Larger shops and more restaurants can be found lining several of the main roads. There is little industrial or commercial action compared to cities such as Birmingham, UK and overall the city has more of a village-like atmosphere. The picturesque 4 miles of waterfront, naturally wooded setting, golf courses and nearby beaches attract tourists, seasonal and year round residents. The City of Dunedin has been recognised for its commitment to the environment, by being awarded the 'Green City' designation by the Florida Green Building Coalition. It was the third municipality in Florida to receive this

esteemed title (Lane, 2008). Dunedin is a prime example of a sustainability and environmentally aware coastal city that is forward thinking in terms of planning and managing resources.

3.2 Hydrogeology

There are two major aquifer systems in Pinellas County; the surficial (unconfined) unit and the Floridian Aquifer. The two aquifers are separated by an intermediate confining layer. The combined depth reaches from the surface to nearly 400m below ground level.

The surficial aquifer is comprised of fine to medium grained sand that grades downwards from shelly sand to sandy clay. At the base of this aquifer in the Dunedin area lies an organic rich very fine sand layer. The thickness of the surficial aquifer varies between approximately 2 to 16m.

The low permeability intermediate unit is approximately 15 to 21m thick and consists of clays, varying amounts of silts and sands, and to a lesser extent, low permeability limestones.

The Upper Floridian aquifer is approximately 30 to 80m thick and is the most productive aquifer in Pinellas County. It consists predominantly of the limestone of the Tampa member of the Arcadia Formation and the upper part of the Suwannee limestone (Leggette et al., 1994). There are further limestone units and sections of the Floridian aquifer that lie beneath the Upper Floridian aquifer, but these are not used as much for abstraction. Figure 4 summarises the geological units and hydrogeology of the area.

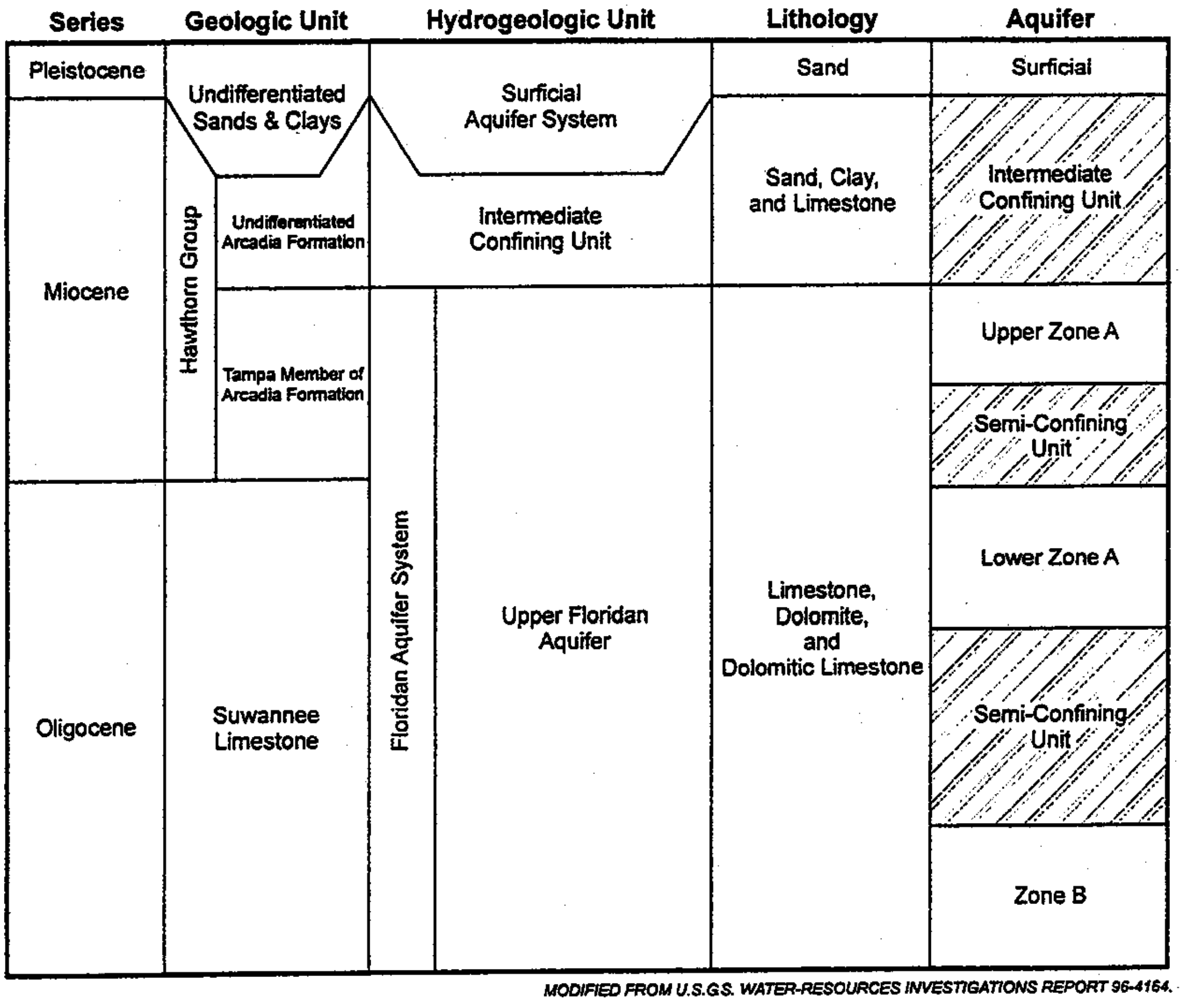


Figure 4 – Pinellas Hydrogeology (Missimer International, 2001)

3.3 Water supply

Most surrounding municipalities in Pinellas County purchase water from Tampa Bay Water, as potable water is a diminishing commodity (City of Dunedin, 1992). The city of Dunedin, is however completely independent in terms of water management. The region relies on its own well field for potable water. The 26 wells in use are all located within the city limits as is the water treatment plant.

The wells abstract water from the Floridian aquifer and this is regulated by the Southwest Florida Water Management District (SWFWMD). In the past the city has had problems with water quality, resulting from aggressive iron laden waters being pumped, along with reduced quantity available and the threat of salt-water intrusion (City of Dunedin, 1992). Since the early 1990's the city has placed emphasis on groundwater resource management, to maintain groundwater that is as low in chloride content as possible. This includes well protection and monitoring of the storm water quality, to limit groundwater contamination via recharge processes (Yeh, 2010a). To ensure a high quality product, the city also built a Reverse Osmosis (R.O) Water Treatment Facility. The facility runs on a 9.5 MGD capacity but is expandable to 12 MGD. Quick calculations show that approximately 77% of abstracted water gets converted to potable water ready for use. The rest is lost to pipe leakage (minor component) and the bi-products of RO (concentrate and green sand filter backwash).

Approximately 11,536 customers are served with water in the city, giving a total of 3.27 MGD (12.4 Ml/d) supplied daily (Yeh, 2010a).

3.4 Systems and Current Sustainable management practices

The City independently owns and operates its supply wells, water treatment plant, water distribution system, sanitary sewer network and waste water treatment plant (Yeh, 2010a). In addition the city owns and operates an extensive storm water collection and treatment network, which consists of man-made and natural drainage channels, drainage pipes and over ground storage areas such as ponds and swales. Here the water has time to recharge naturally to the groundwater system rather than being discharged to St Joseph Sound, or some of the contaminants have time to settle out before the water is discharged. All the above systems are managed by the City Public Works Department.

Dunedin is already forward thinking in terms of sustainable water management. The wastewater treatment plant uses advance biological removal (A^2O) and most of the highly treated water is reclaimed and reused within the city (Yeh, 2010b). The reclaimed network within Dunedin is now extensive and one in four drinking water customers are also reclaimed water users, making Dunedin the city with one of the best reclaimed water systems in Florida. The reclaimed water is only permitted for irrigation use and hence usage varies seasonally. In the dry season near 100% of wastewater is reclaimed and no wastewater discharges to St Joseph Sound, whereas in the rainy season only 40-60% is reclaimed due to the decrease in demand (Stidham, pers. comm., 2010).

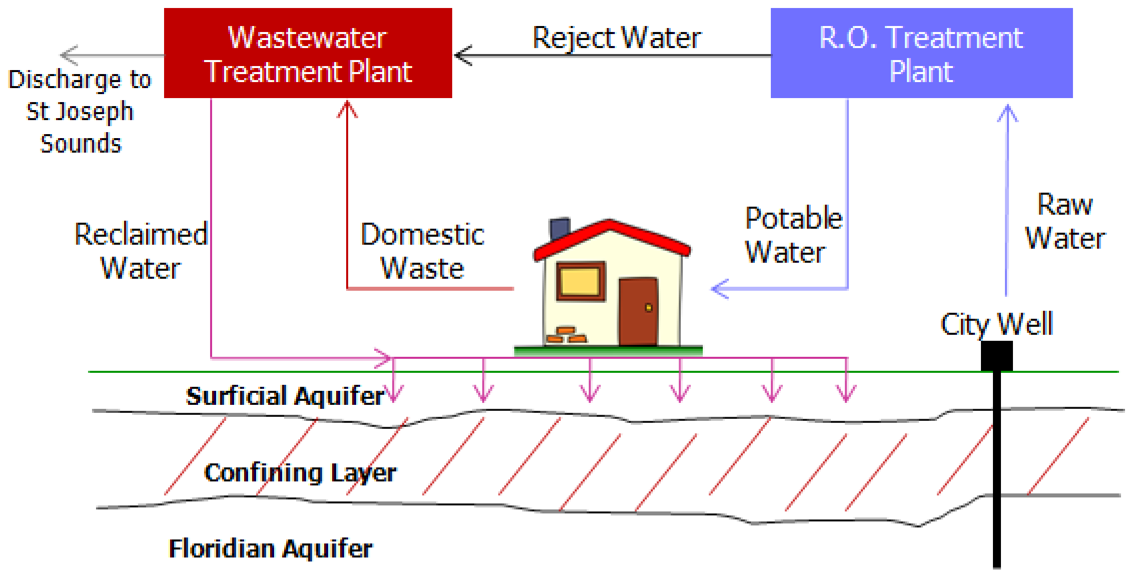


Figure 5 - Simplification of the main water system network in Dunedin.

In times of low demand, pumped groundwater can be sent to reclaimed storage tanks to supplement the supply. It should also be mentioned that the water and waste water treatment plants are intrinsically connected. The two waste streams from the R.O. treatment (the

backwash from the filter media and the condensate stream) are piped directly to the wastewater plant. The WW treatment plant cannot deal with the high levels of salinity from these products all in one go. The water plant therefore has to spread the operation of the R.O. units throughout the day, rather than operating solely at off peak electricity times (Van Amburg, pers. comm., 2010).

3.5 Dunedin and SWITCH

Being the pro-active city that it is, Dunedin has formed strong links with The University of South Florida (USF). The relationship appears to be mutually beneficial in terms of education and research. Dr. Daniel Yeh, Assistant Professor of Civil and Environmental Engineering at USF, saw the potential of the city as a demonstration city for the SWITCH project, and was supported in the application for SWITCH recognition by Tom Burke, the City Engineer.

The collaboration of USF, Dunedin and The University of Birmingham to pilot the CWB model (this project), further convinced officials of the commitment of the city to the SWITCH approach of more sustainable and integrated urban water management. Hence from June 2010, Dunedin was officially recognised as a ‘SWITCH Associate City’, the first in North America (Appendix 1).

4 Methodology

An introduction to the model and its main features has been given above. This section gives a description of the data acquired for the model inputs and the decisions made for the way in which a lot of the data was arranged for model input.

As the project set out to improve and update the model, using the different data set from Dunedin, much of the aims were achieved as work progressed and features that were changed and the reasons for the changes are explained throughout the methodology. A summary of the model updates is then presented in the Discussion.

4.1 Field Visit

A two week visit to the city of Dunedin was completed from the 30^{th} May to the 12^{th} June (2010), and a further one week visit from 10^{th} -17^{th} July (2010). In this time meetings were arranged with city officials from the water treatment and waste water treatment plant, and the planning and engineering department. A vast amount of information and data was collected over the two visits. Time was also spent ground truthing, to ensure that the spatial representation and land cover aspects of the model would be representative. Field work was also undertaken to investigate surface water bodies that were difficult to see from satellite images. The time spent in Dunedin was critical to the successfulness of the project. For many of the model inputs it was expected that it would be too difficult to find appropriate data and many estimates would have to be made. However, the helpfulness of the people and the excellent records kept by the city meant that much more information was gained than expected in this short time. Along with official records and other hard and electronic copies of data, local knowledge was extremely useful for filling in some of the gaps and making estimates.

4.2 Spatial Scales

As described in section 1.4.1 the model accepts land cover inputs on three scales: - unit blocks, mini-clusters and subcatchments. The decision of how much of the city would be modelled was made in the early stages. The choice was between selecting an area of the city and modelling this to a high level of accuracy, or to model a much larger area i.e. the whole city and make more assumptions about land cover and water use. It was decided that the entire city would be modelled. There were several reasons for this choice: - 1) the city is quite small, having an area of approximately only 27km^2, 2) as the model is a scoping model it doesn't work to a high degree of accuracy on the small scale and is created to allow for large scale assumptions, 3) it quickly became apparent that a vast amount of adequate data could be collected on land use, maps and water use profiles for the whole city area, and 4) the assessment of water management options would be much more useful if the whole city were to be modelled, especially as the City of Dunedin is responsible for the water and waste water management of Dunedin, as well as the planning and development of this area.

4.2.1 Unit blocks

For Dunedin it was decided that 30 different unit block types would be defined. This decision was largely based on studies of the city and how land could be split into different blocks that could be represented by a common land cover and water profile. Another key factor in this decision was the available water usage data for buildings which will be described in section 4.3.3.1.

Once the unit block types had been decided on, satellite images from Google Earth, and the area measuring tools in this program were used to measure the features required for input e.g. roof area. This was carried out for several different examples so that an average area for each input could be used. For most unit blocks the number of different examples measured was 10

as this was thought to be a large enough number to give a good estimate of average areas (and had been used in the Birmingham model). However for a few unit blocks e.g. secondary schools, there were not 10 examples to measure, so the maximum amount of examples of that unit block type within the city were measured.

As maps were provided with the reclaimed water pipe network, it could be worked out which areas of land were using this recycled water system. So that this would be accurately represented when it came to inputting water management options, the residential unit blocks created were separated into those with or without reclaimed water.

Figure 6 shows an example of one of the unit block types – ‘Large house, large garden, with reclaimed water’ (unit block type 1).

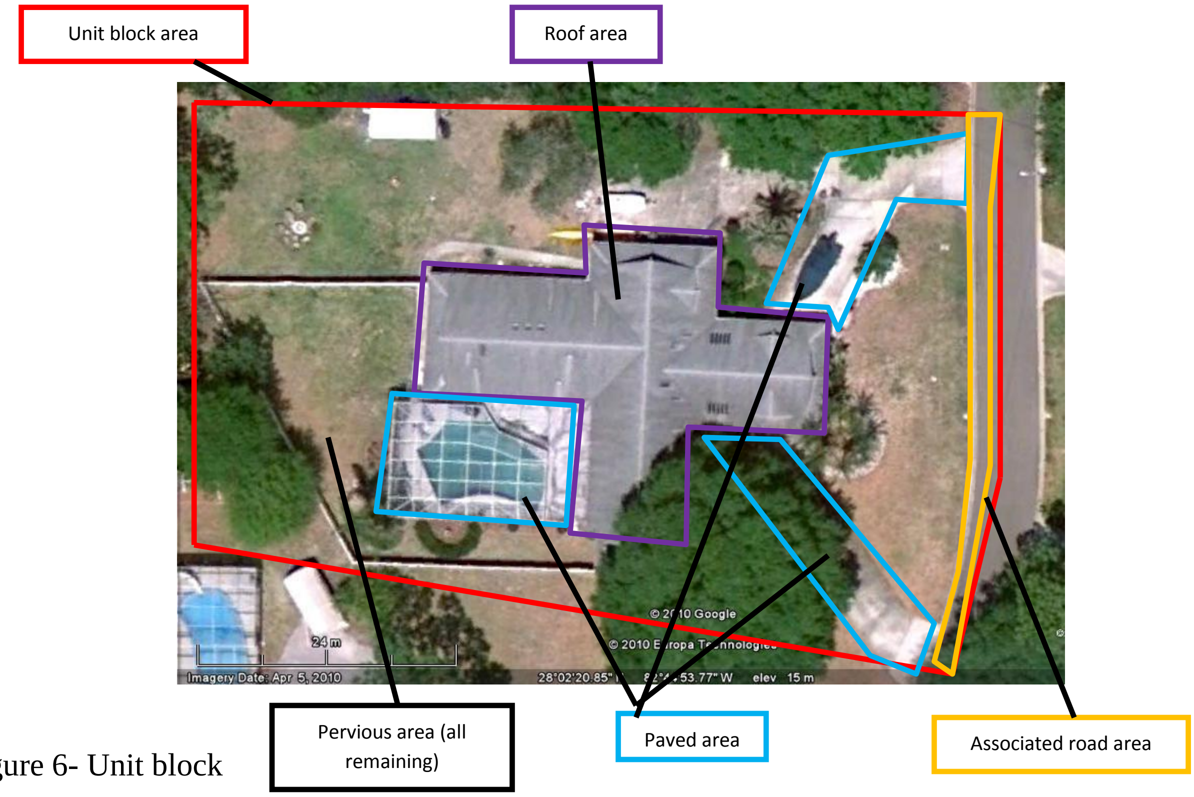


Figure 6- Unit block

The list of unit block types is presented in Table 2. For the full list of areas measured and calculated for each unit block type please refer to Appendix 2.

Table 2- Unit block descriptions	
Unit block description	**Unit block number**
Large house, large garden, with reclaimed water	1
Large house, medium garden, with reclaimed	2
Medium house, medium garden, no reclaimed	3
Medium house, medium garden, with reclaimed	4
Small house, medium garden, no reclaimed	5
Apartments	6
Mobile home	7
Nursing home	8
Condos	9
Hotel	10
Marina	11
Hospital (+physicians' offices)	12
High school	13
Elementary school	14
Office	15
Church	16
Retail, strip shopping mall	17
Retail, small shop	18
Restaurant/eatery/drinker	19
Industry	20
Stadium	21
Golf Course	22
Public Open Space (POS) – recreation	23
POS – wooded	24
POS – POS	25
Road – main	26
Road – small	27
Recreational – spray ground	28
Large house, medium garden, no reclaimed	29
Supermarket	30

4.2.2 Miniclusters

For fast representation of the land cover ArcGIS was used to plan out 'minicluster' areas which each consist of a unit block type. Once this was completed and attributes assigned appropriately the program 'shapedump' was used to output the vertices of the polygons drawn. This is a simple process as long as the order in which the miniclusters are arranged in the attributes tables is correct. The process of working out the exact method which was required to get this order correct for the input files, along with finding the correct way of

labelling the clusters (which was labour/time intensive and involved redoing much of the spatial mapping) highlighted the need for clear instructions to accompany the model for this particular aspect of the work. A lot of time would have been saved here.

The field visit provided excellent GIS maps of the city, including parcel data showing building plots, the pipe networks for the different water systems and a whole satellite image of the city (to a high standard resolution) and proved extremely useful for this section of the work. In total 338 miniclusters were mapped. Figure 7 shows one example minicluster. This particular minicluster is made up of several ‘mobile home’ unit blocks.

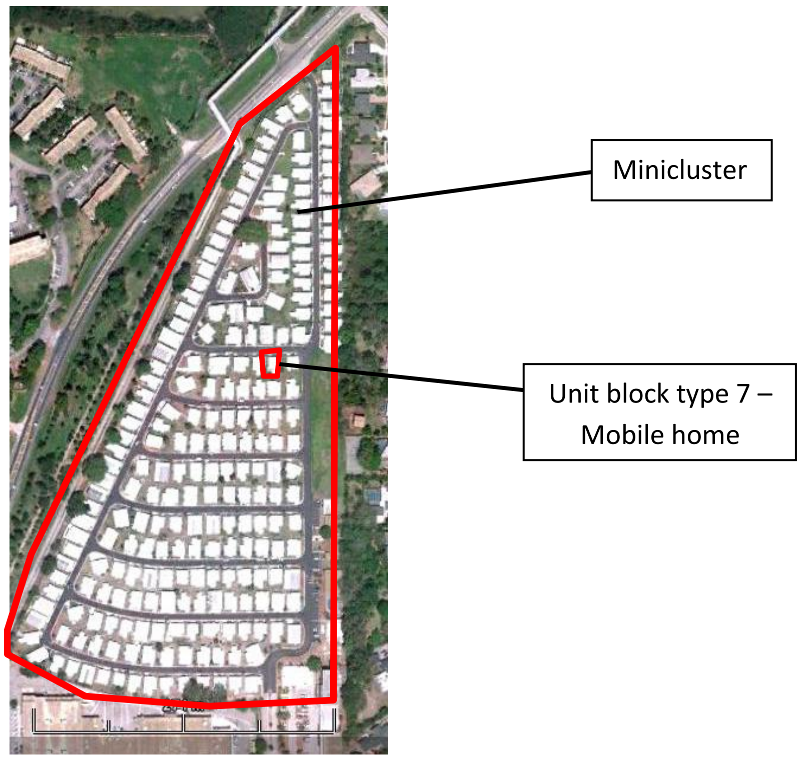


Figure 7 – Example minicluster

Figure 8 shows the colour coded miniclusters across the city.

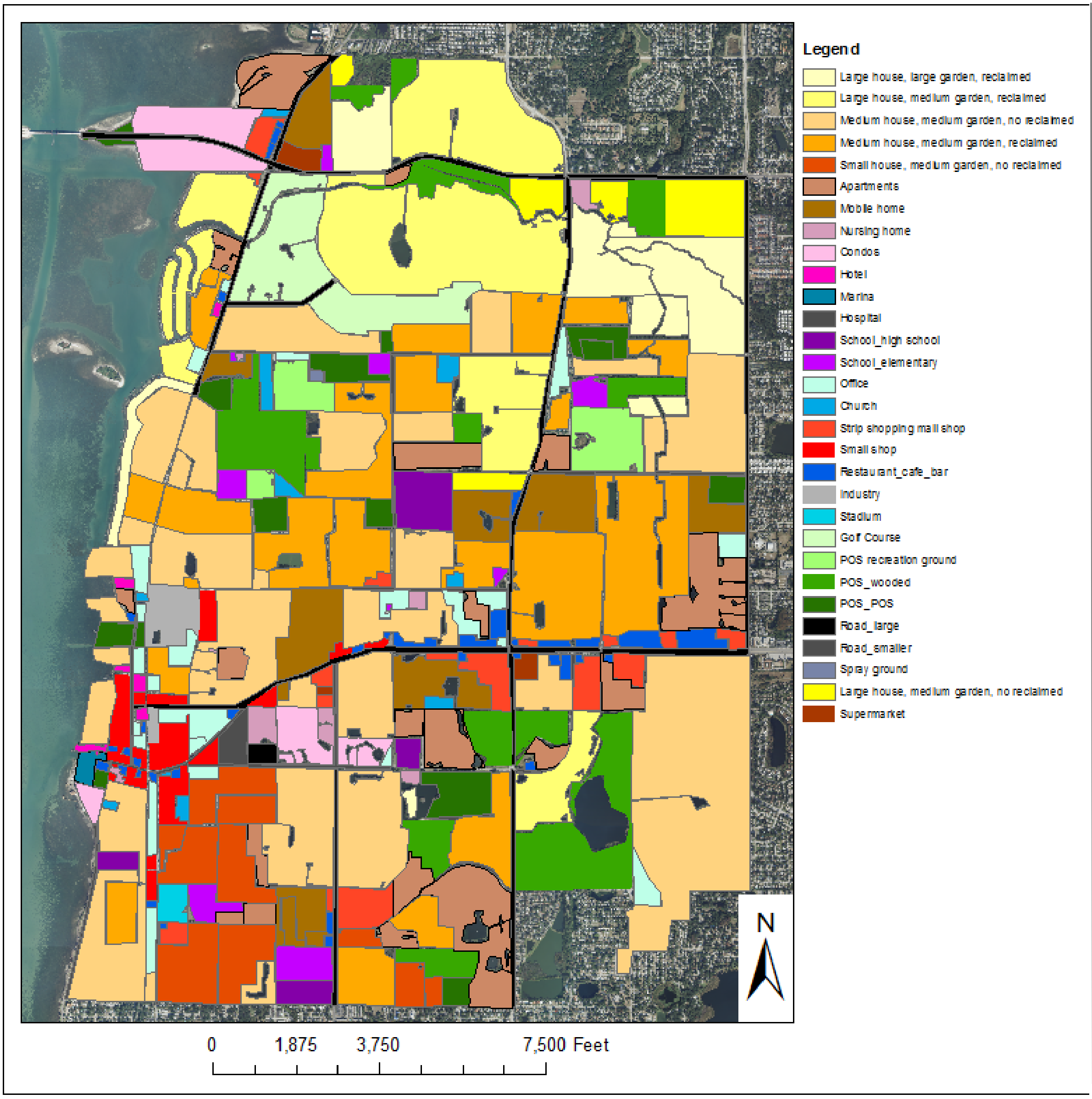


Figure 8 – Dunedin minicluster map

4.2.3 Subcatchements

The large scale subcatchments were actually decided upon first before the miniclusters mapped, as the miniclusters lie within and cannot cross subcatchment boundaries. They were created so that the waste water and storm water flows could be easily modelled in CWB.

A total of 15 subcatchments were created for Dunedin. This was decided upon because of the waste water system. In Dunedin, the sewage and waste water is completely separate to storm water. All waste water from buildings flows by gravity to one of many lift stations. From there it is pumped to the central waste water plant within the city limits. Figure 9 shows and example of a lift station.

Figure 9 - Lift station #1

Data sets showing daily inflows and pumped discharges from these lift stations (Appendix 3.1) were collected from the Waste Water Treatment Plant. With a map showing sewage pipes and lift stations (Appendix 3.2), along with a flow chart showing the sequence of flows between lift stations to the waste water treatment plant (Appendix 3.3), it was ideal to base the subcatchments around areas served by the different lift stations.

Figure 10 demonstrates how the subcatchments were created. The flow diagram was used carefully together with the sewage pipe network map. As some lift stations only served a very small area before flowing onto another lift station, several lift stations were grouped together. The decision process here was affected by the model rules that flow from one subcatchment can only go to one other subcatchment and the flow direction must go from a smaller to a larger numbered subcatchment.

Figure 11, shows the subcatchments as they were translated onto the city map in arcGIS.

The decision was made not to include Honeymoon Island within the model (though it is serviced and part of Dunedin), as the land has several buildings that little information was collected on but most of the land cover is national park where there is little water usage. The groundwater would also be difficult to model for this spit of land as more careful calculations of the freshwater/saltwater interface would be needed. As there was no hydrogeological data available on this it seemed of little use to create a poor representation by guessing. Lift station 22, serves the whole island area so when it comes to calibration it must be noted that the amount of waste water coming back from Honeymoon island must be deducted from the total wastewater flow out of the area (through the waste water treatment plant). This may be a considerable amount and must be taken into account because although there are not many buildings serviced on that area of land, several of them are high rise. Also information and insight gained from visiting the water treatment plant showed that some flushed water from the water treatment plant (flushing used as a process to decrease chances of tank water chemical contamination) is disposed of at this lift station.

Figure 10 - Sewage lift station flow chart and assigned subcatchments.

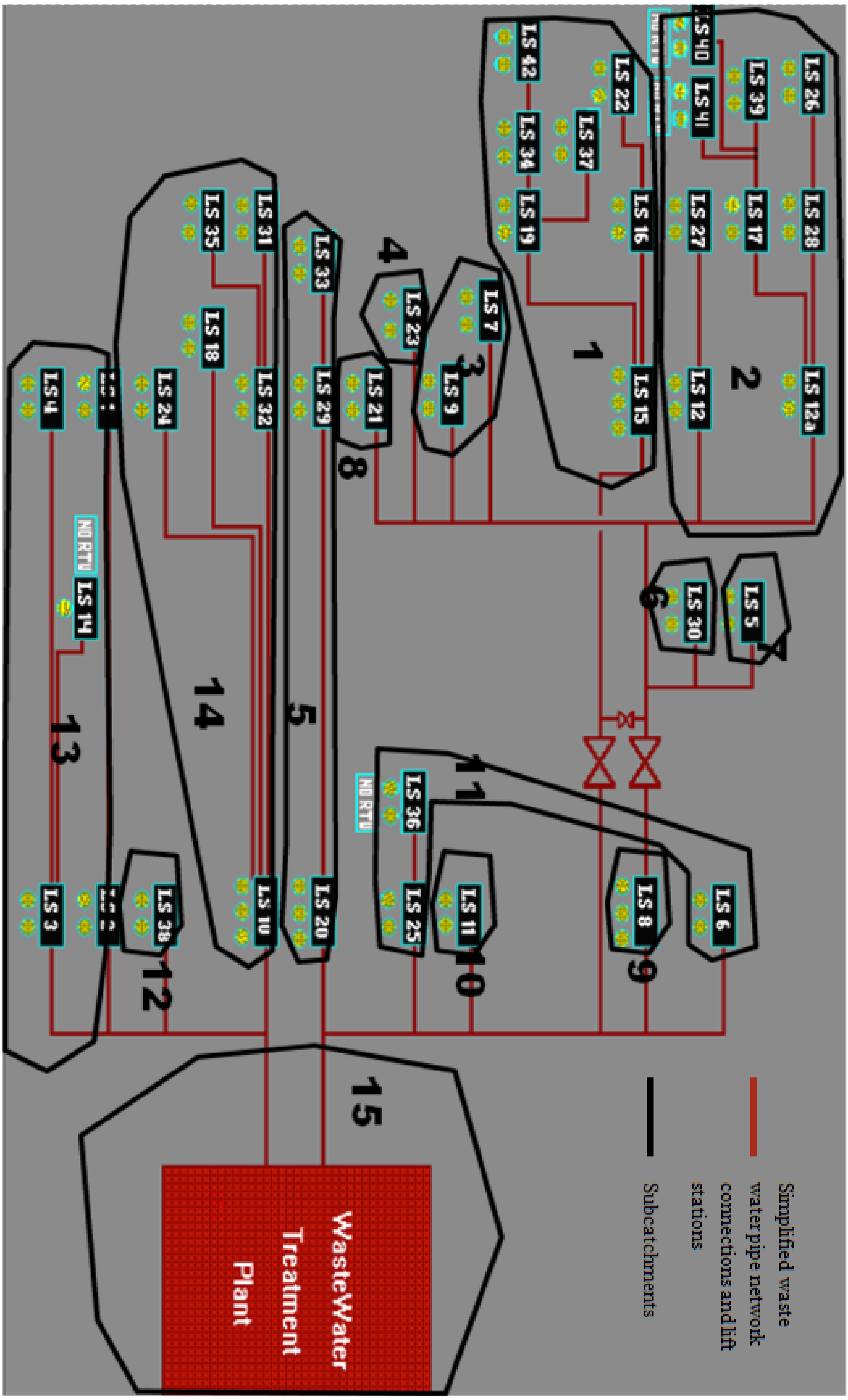
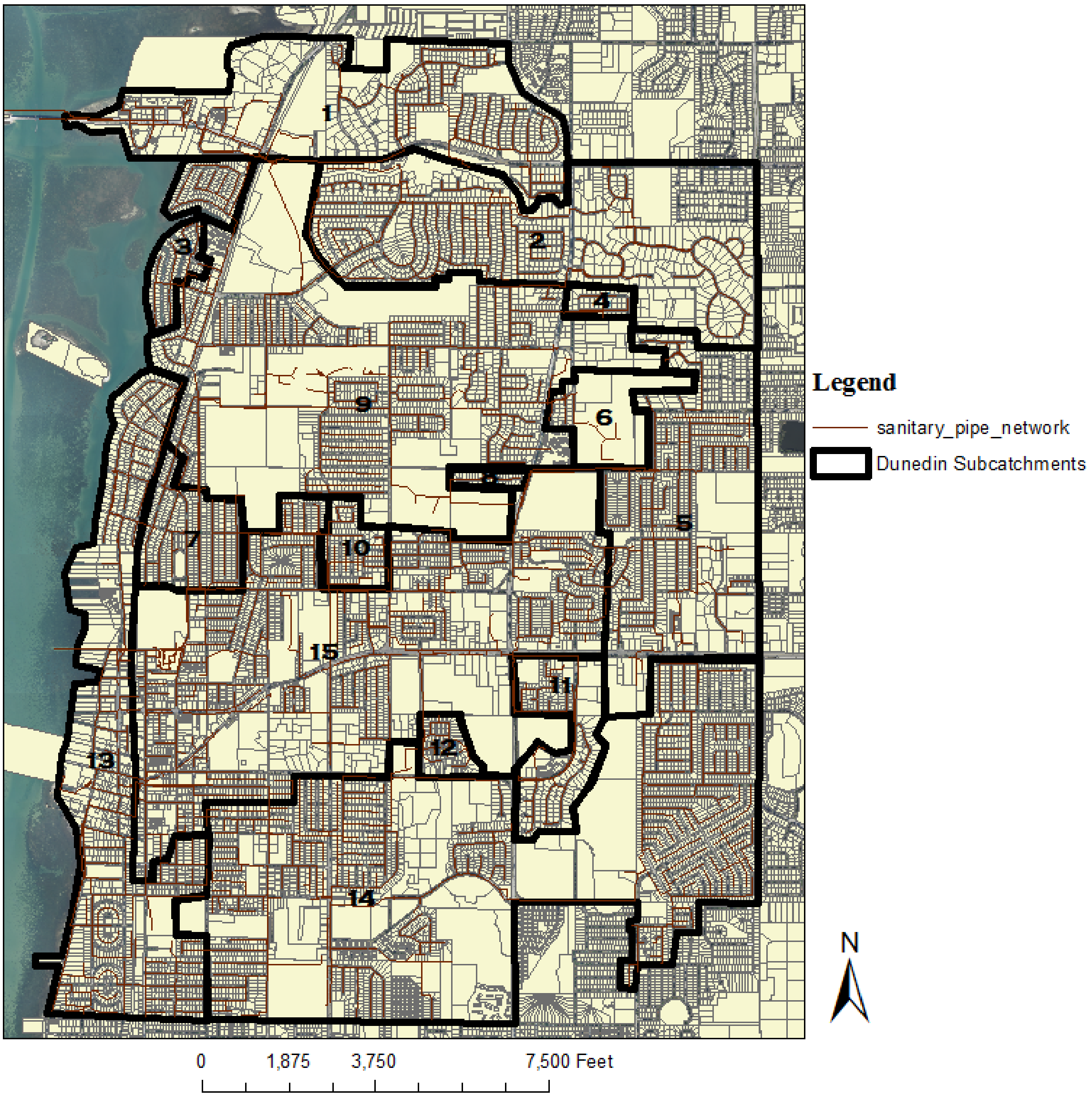
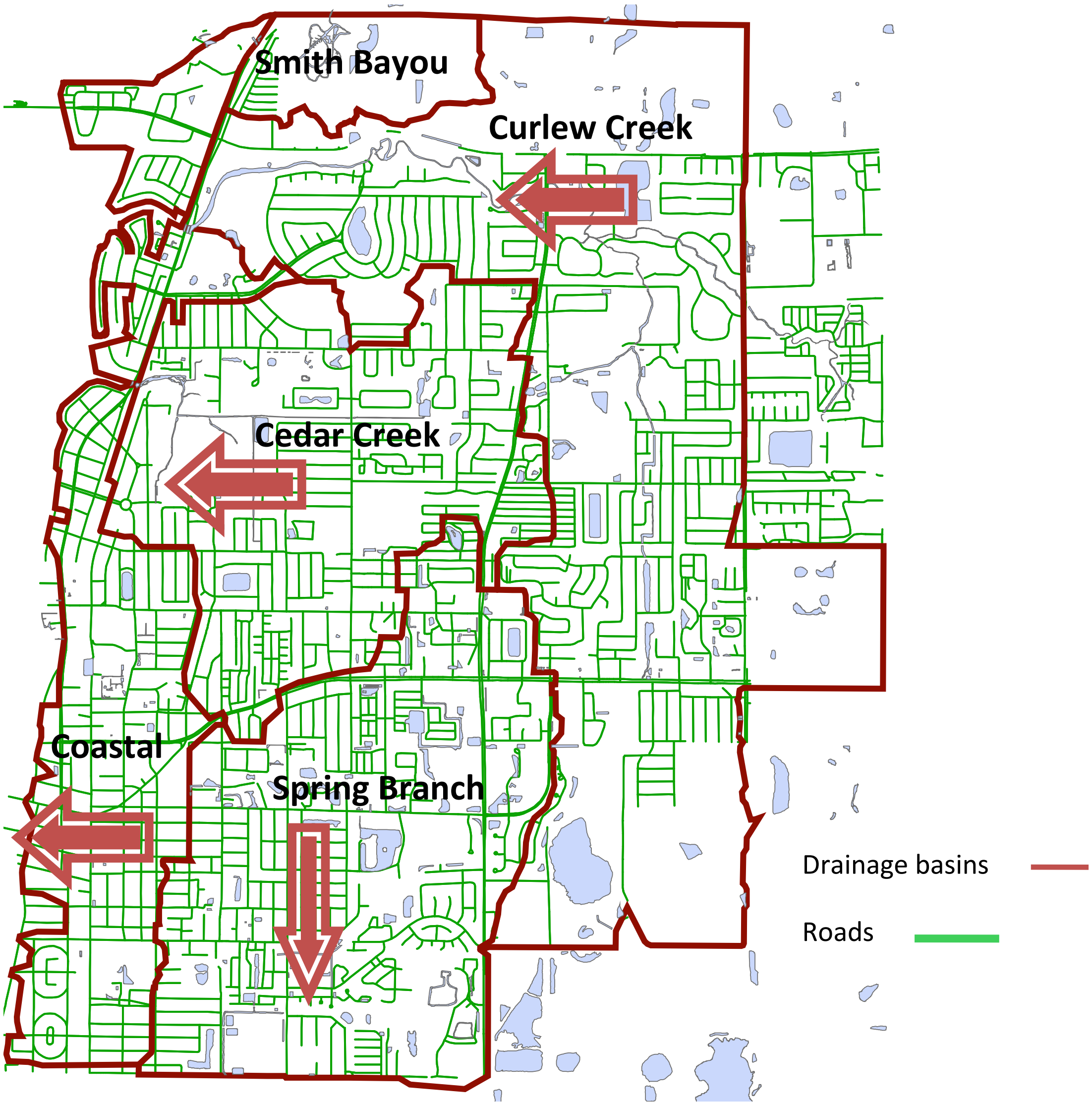


Figure 11 - Subcatchments based on waste water pipe network and lift station location.



The storm water flows were a little harder to define within these subcatchments. Storm water from runoff in the city is directed by a network of drains and pipes but these are interconnected with surface water bodies, some natural and others that have been modified. There are 5 main drainage basins within Dunedin: - Cedar Creek, Curlew Creek, Spring Branch, Coastal and Smith Bayou (Figure 12).

Figure 12 - Drainage Basins



By overlaying maps the direction of storm water flow from the subcatchments was estimated. Again this was limited by the numbers of the subcatchments as flows can only go from one subcatchment to a single other subcatchment and have to flow from a smaller to higher numbered subcatchment. It is thought that this worked suitably well because although flow directions for the storm water were largely different to those of the wastewater, much of the storm water would simply flow out of the area. In this case the water would flow to subcatchment '0', as this is within the rule limits i.e. the water disappears from the system.

4.3 Data inputs

CWB has numerous input files. Here it is explained how data was collected and processed for each input file in turn and any limitations on data collection where default values have been used. Part of the methodology involved recognising when certain input files would not work for the Dunedin system and suggesting and making updates to the input files accordingly. This is explained throughout this section.

4.3.1 Study_Area

As it was know that there isn't a water shortage in the city, the % demand suppliable was set to 100. Energy and cost input values were left as defaults as these won't be considered for this project.

4.3.2 **Subcatchment Flows**

The subcatchments were created as explained above and flow directions of the waste and storm water assigned using the appropriate subcatchment numbers.

4.3.3 Unit_block_defaults

The unit block descriptions including areas or roof, pervious space and paved space were created/calculated as explained in section 4.2.1.

The effective roof and paved areas (area of that land cover which drain directly to the storm water system) were assigned after undertaking ground truthing of the area and studying the different unit block types. It was found that the majority of residential buildings had completely non-effective roof areas. Many had guttering siphoning water from the roof, however these gutters were never directed to a drain and water simply flows onto the garden or paved area, some of it eventually reaching the road (Figure 13). The paved areas were the

same, though for many of the non-residential type buildings there were some drains and an estimate of the proportion of drained paved area was made for each unit block type.

Figure 13 – Non effective roof guttering

Roof and paved ‘initial loss’ (due to evaporation) were left as the default values as no data could be found on this. The value was likely to be incorrect as it was used for Birmingham, which has very different climate and evaporation potential than Florida. Defaults were also used for the ‘trigger to irrigate’ input. These values would therefore require monitoring when calibrating the model.

The proportion of pervious space irrigated was estimated again from in depth studies of the areas. Most residential and several of the other unit block types fully irrigate their garden space – including all lawn area. Many of these values were therefore set to 1. The percentage of public open space, woods and roads were also estimated in a similar manner. Most

‘proportion of POS irrigated’ inputs were set to 0 and ‘trigger to irrigate POS’ defaults were used for the few that were irrigated with similar reasoning to the above.

As Dunedin receives all its potable water from the well field within the city, this will be accounted for within the management options of the input files. The ‘water imported’ values were therefore set to 0.

Occupancy for housing was set to 2.31, an average value supplied by the water department (Appendix 4.1). For other types of residential buildings e.g. apartments/mobile homes, the value of 2.01 was given by the water department. This was used for mobile homes. As the unit blocks for apartments included a certain area and the building in that area would have included more than 1 apartment, this value was multiplied by the number of apartments thought to occupy the average unit block area. This was therefore a rough estimate. Occupancy estimates were made for several other unit blocks but most values were taken from census data or websites giving information of number of employees, attendees or rooms (see list of references).

The proportions of hot water assigned for different uses was set to 0 as this figure relates to energy calculations which are not being considered here.

‘Split usage’ was used in this model. This was applied rather than ‘residential’ as the detailed descriptions of amount used for different appliances could not be found to a high level of accuracy for all the different unit blocks within the time limits of the project. The other main reason was that as energy and cost were not being considered, assigning water use to the categories of ‘toilet’, ‘kitchen’, ‘bathroom’ and ‘laundry’ was thought to be an adequate method for modelling the amount of water being supplied to the residential units, and flowing through to the waste water system.

4.3.3.1 Automatic Meter Reading (AMR)

On the field visit, when unit blocks were being decided upon, assistance was provided in choosing 'typical' examples of the unit blocks considered (local knowledge of great help). Dunedin is very advanced in the fact that it has installed automatic meter reading (AMR) devices throughout the city. The devices monitor water supply to buildings allowing hourly usage data going back 2.5 years to be downloaded for any of the 22,000 meters in the city. The 'typical example' unit blocks that involved water usage were selected and data downloaded from these locations (Appendix 4.2.1).

The data were processed by calculating average daily usage for each unit block type (Appendix 4.2.1, 4.2.2), ensuring that the calculations only commenced from the time when the meter was switched on. For some locations, several meters monitored supply so average values were added together. For those properties linked up to the reclaimed network, this usage was also downloaded and average usage calculated. This was not however added to the average indoor usage for each unit block, as this water would only be used for irrigation. Depending on the type of meter that recorded supply, multiplying factors had to be used for some data. (TC code 10 (1) - no multiplying factor, TC code 100 (2) – multiply all values by 10 and TC code 1000 (3) – multiply all values by 100).

The calculated total usage values for each unit block were divided by the occupancy rate and then split between the 4 usages (toilet, kitchen, bathroom, laundry) and input into the model. The percentage split between these usages was taken from the AWWA report (2004), for residential units. For other unit blocks the default percentage distribution from the Birmingham model was used where it could be. For unit blocks that were not included in the Birmingham model estimates of the split usage were used.

It was noticed that there was no input option available for water that is supplied to a unit block but is then used or transported out of the system. The main example of where this is a problem lies in the industry unit block. In Dunedin the main industrial unit block is the Coca-Cola factory where Minute Maid orange juice is made. The other main industrial unit block is a brewery. Both these example use water in their products in large quantities so effectively this water enters the industrial unit block and then leaves the system completely as it is transport out of the area and consumed. Discussions with CWB creators revealed that there is a setting within the model code which could account for this, but that it is currently 'switched off'. This is an area of the code that must be altered and an input file created so that this type of water use can be defined for each unit block.

The availability for such detailed water usage data was unexpected but goes to show that latest advances in water management technology can be used to get more accurate data for inputs to the model. However, although it was excellent to get examples of usage for the different unit blocks rather than using estimates, only one value for each unit block type was acquired (this took one whole day for a city employee to do as the data from the AMRs have to be read using infa-red technology, that required the data reader to be in the vicinity of the meter). It is possible the buildings chosen didn't give supply data that was representative of all similar buildings. The data was checked to make sure nothing seemed too anomalous but there was no way of telling the representativeness of the data without comparison to similar unit block examples. A few of the readings were discarded as they clearly showed that either the meter wasn't working properly or there had been a leak at that particular location. For those that were discarded, a second example dataset was arranged and collected on the second field visit. It was decided nonetheless that the data should be used in the model as it was more likely to be representative than using estimates. This is especially true for unit blocks such as hotels and the hospital as the values were given for those buildings of known

occupancy and areas, which had specifically been used as the unit block descriptions for this particular model. The accuracy must however still be questioned and taken into consideration when the model is calibrated/validated.

4.3.4 UB_Appliances

These were left as default values as split usage was used rather than residential and energy and cost not considered.

4.3.5 UB_Variable_Occupancy

The values for occupancy were kept the same throughout the year. The reasoning for this was that when questioned, city officials informed that overall the occupancy in the city varies little throughout the year. Although there is a tourist industry, the movement of people into the city in the summer is counterbalanced by the retired population that only come to live in the city in the cooler winter months.

4.3.6 Minicluster_defaults

15 parameter sets that coincide with the different subcatchments were created for ease of use. ‘Surface runoff as inflow proportion’, the amount of runoff going into sewers was set to 0 for all parameter sets as the waste water and storm water system are completely separate in Dunedin.

Sewer exfiltration proportion was kept at the default value as this information was not found. Sewer infiltration data (although not required in this section) was investigated using data collected from the Waste Water Department. The lift station records of inflows and outflows along with rain gauge data from each lift station were used to show that there was definitely an influx of water in some of the pipe networks in times or after heavy rainfall events (Figure 14, Section 7.1.1). An input function could be required to allow pipe infiltration, or the

information could simply be taken into account during calibration. The subcatchment boundaries based on lift station areas were useful here as some pipe network areas were known for having more infiltration than others, and this could easily be assigned to subcatchments.

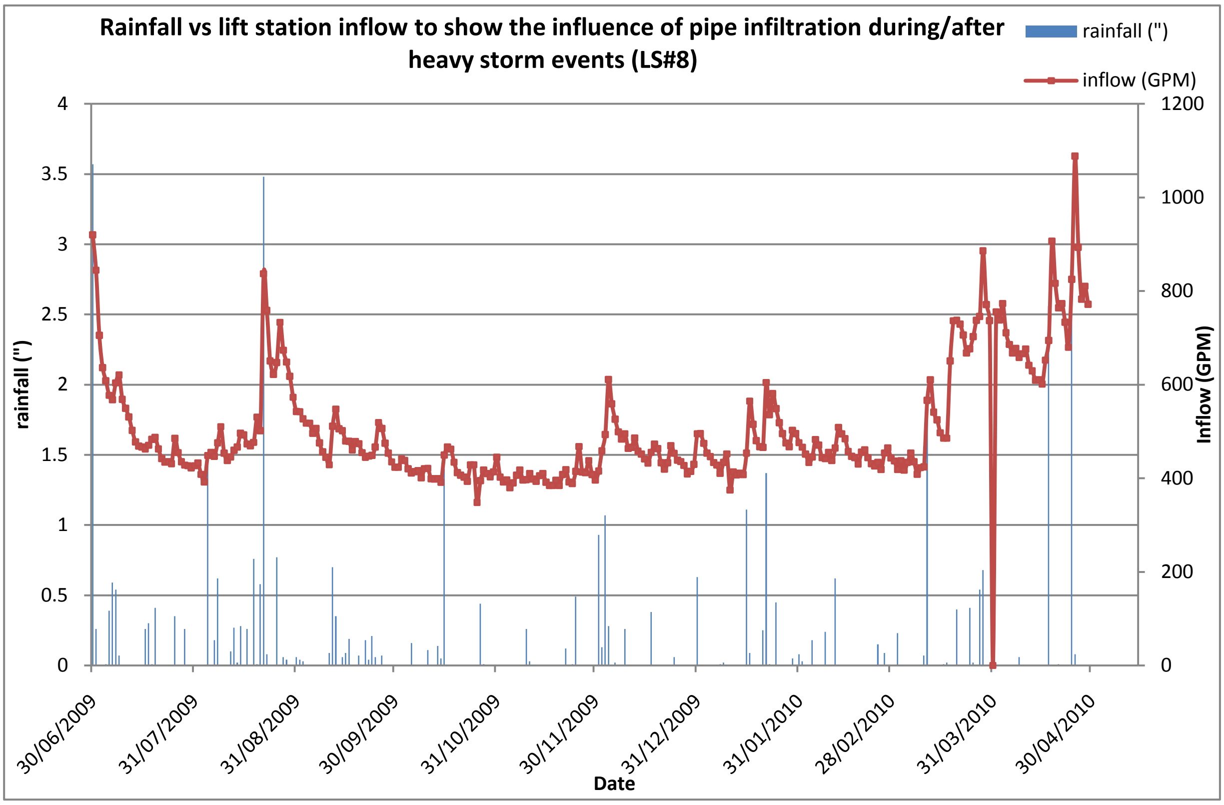


Figure 14 – Graph to show the LS#8 rainfall and waste water inflow

Infiltration store recession coefficients, woods intercept, woods evapotranspiration, road initial loss, and recharge and infiltration index values were left as defaults due to lack of available data.

Leakage proportion from the potable water supply pipes was set to ‘0.13’. This value was an estimate made by the Water Operations Manager from a study he had undertaken of the system. When this figure was presented it was mentioned that due to uncertainty it was more

likely to be less but no lower than 0.08, so this figure could be altered in the calibration process.

The effective road proportion was set to ‘1’ for all parameter sets. Ground truthing of the city showed that there were a few roads that did not have storm water drains; however the majority of roads did (Figure 15). The roads that were not lined with storm water drains appeared to be distributed randomly throughout the city so it would not have been practical to assign a minicluster parameter set that allowed for this, as it would have to be assigned to one particular area and this would not be representative. All roads were therefore said to be ‘effective’.

Figure 15 shows a typical roadside drain. Figure 16 shows another common roadside guttering feature that can be found in Dunedin. This is a type of roadside guttering that directs water to drains, but also has cracks in it to encourage infiltration. There is no function in CWB to allow for this, but with a more detailed study a certain amount of road surface could be assigned as ‘pervious paving’. As the majority was impervious this management option was not included.

Figure 15 –‘Effective’ roads

Figure 16 – Infiltration drains

4.3.7 MC_Assigns

The list of miniclusters were simply assigned their unit block type and subcatchment number by copy and pasting values from the attributes table in arcGIS (in the correct order).

4.3.8 MC_Groups

Here groups of miniclusters were defined for ease of input for the management options. These are discussed alongside the large borehole and large waste water recycling options in sections 8.2 and 8.3.

4.3.9 Soil_Types

The soil type file will likely be updated in the new model so that inputs are more standardised and simpler e.g. by using USGS soil type classifications and properties. However, these updates have not been finalised so the input data was arranged using the original model input format.

The 'websoilsurvey' (USDA, 2009) was used to find soil types and properties for Dunedin. Although this showed there to be several different soil types within Dunedin, the different types were scattered across the city with no clear boundaries. Almost all soil types appeared to consist of fine/very fine sand. One soil type 'fine sand' was therefore defined for the whole city area. The two-layer model was chosen over the partial areas model, as the partial areas model is more suited to arid and semi-arid climates (Last, 2010b). Porosity values were used for soil capacity inputs (this may be an over estimate as not all pore space may be capable of containing water, however this is the nearest possible estimate with the data provided). Total soil and water depths were taken from USDA (2009). Other input values such as drain factor and drain maximum were left as default values as there was no information available that could be used as or used to estimate these inputs. Sensitivity testing of the soil inputs will

likely be required when the model is complete. The model will definitely benefit from having a more standardised soil data input section and clear instruction on how to estimate input parameters from typical soil properties that can be found in literature.

As the groundwater in the city area is used as the supply of water to the city, it will be very important to get good recharge estimates for the Dunedin model. The soil input file is likely therefore to be vital. When the model is completed it may be found that a much more detailed representation of the city soils is required. Although it appears from USDA (2009) that the soil types are very similar, city officials warned that the soils could show very different infiltration characteristics. No more soil maps or detail was provided, but this may require further investigation.

4.3.10 Climate_Data

Rainfall data was provided by the Waste Water department who have a series of rain gauges located across the city sewage lift stations (Appendix 5.1). The model only takes one value for the city for each day. It was thought that perhaps the model could be improved by including a Theissen polygon code or similar so that better representation of the rainfall distribution across a city could be used in the water balance. A cumulative mass plot of the rainfall data was created first to investigate if the rainfall differed a lot depending on location (Figure 17, Appendix 5.2). It turned out that it actually didn't. Figure 17 shows that the rainfall appeared lower for two of the coastal lift stations (#1 and #22). However, other coastal lift stations showed values similar to the average. The seasonal changed in rainfall are similar for all lift stations. A simple mean value of rainfall was therefore used for the city and input into the climate_data section. The inclusion of a Theissen polygon code could be an improvement to the model in the future, however its use would be dependent on having a network of accurate daily rain gauges across the city being modelled, and this is unlikely for

many developing cities. As the model is a scoping mode and inputs are supposed to be easily attainable and many are based on averages, a mean rainfall is thought to be suitable.

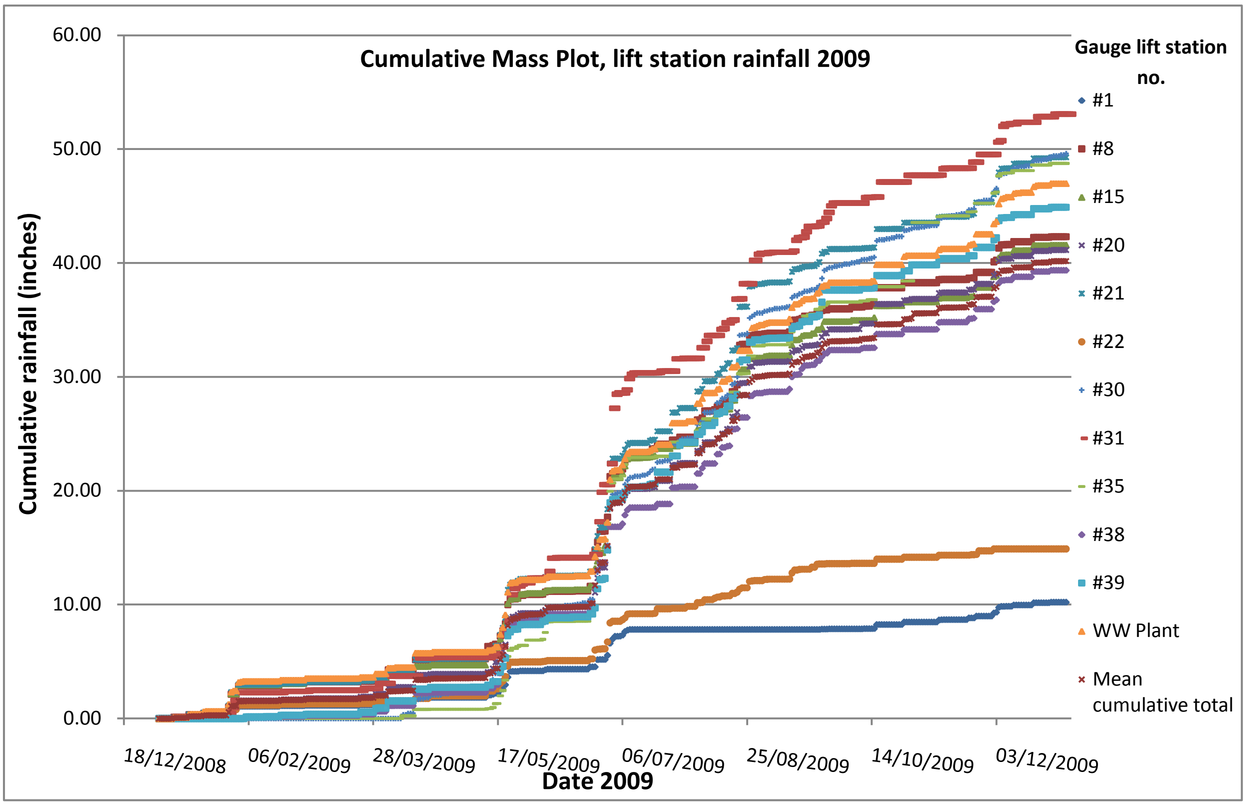


Figure 17 – Cumulative mass plot of Dunedin lift station rainfall.

USGS evapotranspiration was accessed online (USGS, 2010) and used for the potential evaporation values. Leakage correction values were set to 1 as no-one in the city had any clear cut data on the differences in pipe leakage throughout the year.

4.3.11 River_input

The two main rivers in the city were modelled. They were split into sections so that flows from tributaries from each could be simulated appropriately. In total the rivers were split into 9 river sections and 24 segments (the model allows the user to define the river properties by splitting them into segments). These were drawn in arcGIS (in the correct order –

waterbodies always flowing to one other waterbody of a higher number), and the shapedump program used to export the vertices.

The properties of the segments including, widths, depths, bank height and riparian zone width, were adapted from the Master Drainage cross section plans of the river sections (City of Dunedin, 1983), and field observations. The Manning coefficient was estimated from field observations, as was the initial depth of water, hydraulic conductivity and flow rate.

The thickness to the aquifer had to be calculated. First the river bed height was found using a combination of the Master Drainage Plans (City of Dunedin, 1983), or observed bank heights in unison with ground elevation contour maps of the city. The aquifer depths were a little less certain. As explained in section 4.3.19 there were not many measured water table depths throughout the city. The known depths to the aquifer for limited locations were imported to MODFLOW, and the program allowed to interpolate between these points to give a smoothly varying aquifer profile. Aquifer depths at the location of the river segments were then subtracted from the river bed depths to give depth to aquifer. As the model was being updated to allow for more aquifer layers, the question had to be asked, did the model automatically accept the topmost aquifer in the 'depth the aquifer'? It was found that it did and that the code therefore did not have to be updated in this section.

The current version of the model accepts a gradient definition for each river segment. This is in the process of being updated so the top and bottom elevation of the river segment will instead be input. There are complications concerning how the model will then calculate the gradient, because although the river vertices give the area and shape of the river segment, the segment is unlikely to be a straight line between its highest and lowest points and could have a much lower gradient then that which a simple point to point calculation would result in. The new method has been left to the discretion of the model writer.

4.3.12 River_receive

There river segments defined were described further by inputting the miniclusters that they were receiving water from. The proportion of each minicluster draining to the river segment was estimated by eye from the maps (this was limited to 10 miniclusters per segments, putting a restraint on the segments lengths). Some segments, though adjacent to several miniclusters did not actually receive water from them by drainage. The GIS shapefile of the storm water drains, provided by the city, was extremely useful in this instance.

4.3.13 Lake_input

Dunedin has an abundance of surface water bodies. Most are storm water ponds and were defined as part of the water management options. There are however several larger water bodies that were classed as lakes. Although most were not connected by rivers and were in fact used as some form or other of storm water management, the reason for them being defined as lakes is that they are thought to be connected to the aquifer (and the depth to the aquifer can be defined at 0 within the input files for lakes, but not ponds). There was little information available on which waterbodies were connected to the aquifer and which layers, but the ones outlined in this input file are the ones that were definitely known to be spring fed by the lower aquifer.

Ground truthing showed these to be in slightly lower lying areas and it is thought possible that the lakes have formed in former sink holes. Here the intermediate confining layer could have become fragmented allowing for the almost artesian conditions and water seeping up from the lower aquifer.

Lakes were drawn in arcGIS and the vertices exported using shapedump. Properties such as weir height, depth, initial depth etc. were estimated from maps, satellite images, and field

observations. Hydraulic conductivity of the bed was estimated using the known soil and rock types and translating these to lake bed sediment properties. The weir coefficient was set at the default value of 2.7 as instructed by Last.

4.3.14 Lake_receive

The miniclusters and the proportions of each, draining to each lake were estimated from maps. Again, great use of the storm water pipe map was made.

4.3.15 Canal_Info

The number of canals was set to 0 as there are no canals in Dunedin.

4.3.16 Large_Pond

Here the pond default sets were defined. The original model only allowed the maximum depth and the permanent water volume to be input to describe the volume of water in and the potential capacity of the ponds. This made little sense as (especially in an area with so many ponds) it is unlikely that ponds volumes would be so similar that you could simply assign a volume that could be used for all of them. The term ‘permanent water volume’ is also misleading as this would imply that the water level in the pond never changes. This part of the model required updating so that the initial depth of water in the pond could be used in unison with the exported vertices (giving surface area) from arcGIS to give water volume for the ponds.

Due to the abundance of ponds as methods of surface/storm water management it was important to get these input files working correctly for Dunedin. Field observations showed that most of the ponds always had some water in them but to a shallow depth. There is one large pond in the NE of the city that is a detention pond, i.e. it is usually dry, and so a default

set would be created for this pond to allow for initial depth of 0. Figure 18 shows an example of one of the many ponds in Dunedin, and its connection to the storm water drainage system

Figure 18 – Stormwater pond

4.3.17 Pond_receive

For each pond a default set was assigned and the minicluster number that the pond resides in given. The minicluster and proportions draining to them were assigned similar to the lakes and river segments.

4.3.18 Vertices (MCs, rivers, lakes, ponds)

When all shapefiles for the above spatial inputs had been created the program ‘shapedump’ was used (Appendix 6), to output the shape vertices. These files were then transferred to the correct excel input worksheet. It is of vital importance that the polygons created in the shapefiles are done so in the necessary order e.g. the MCs must be in order of subcatchment

i.e. from say 1 to 10 in subcatchment 1 and the from 11 to 13 in subcatchment to an so on. Rivers and lakes must be output in flow order.

4.3.19 Aquifer

The aquifer inputs were first calculated by simulating the groundwater flow in MODFLOW. As the aquifer which Dunedin sources its supply water from lies beneath a confining layer topped by the surficial aquifer, it was clear from the start that the aquifer input file in CWB was not sufficient to model the system. Anything other than a simple one layer unconfined aquifer could not be accurately represented. The model code and input file for the aquifer sections were therefore updated so that more than one layer could be represented. The old model was also extremely simple in that it did not allow for groundwater flow out of the model area. The only loss of water from the groundwater system could be through surface water bodies and drainage. This was updated so that constant head boundaries could be assigned to appropriate grid cells, allowing a better representation of groundwater flow through the area.

A three layer model in MODFLOW was therefore created (Appendix 7.1). The 35 x 40 grid of 250m sized squares was set up. Well Head Protections Plans (Villalpando, 2008) from the City of Dunedin were used as the main source of information for the model. Detailed descriptions of the layer heights at the 26 borehole locations were provided as well as estimated radii of influence for each of the boreholes, which all lie within the city limits (maximum of 500m) (Appendix 7.2). Information gained from meeting the city hydrogeologist outlined that the recharge in the area was largely from rainfall in the city area and the movement of water through the surficial and confining layer. The grid size therefore didn't have to cover much area outside the city limits, as recharge and pumping radii could be accounted for within the area.

Little information was found on the saltwater/freshwater interface so a constant head boundary of 0 was set for all layers along the coastal Western side of the city and ‘no flow’ cells assigned further to the West. A rough sketch map of piezometric contours from the Dunedin 2025 - Comprehensive Plan (City of Dunedin, 2008) was used to assign a varying constant head boundary for the lower aquifer around the rest of the model edges. The confining unit and surficial aquifer were assigned no flow boundaries around the model as this gave the best results for head values when the model was run. This can be justified because although it is more likely that there would be some flow (especially in the surficial aquifer) around the model edges, we are assuming that none of the recharge comes from surrounding areas and a lot of the water travels straight down through this shallow aquifer.

The bottom and top depths of the aquifer beds were taken from the Well Head Protection reports as mentioned. These were imported as xyz files and the model allowed to interpolate between the points to give smoothly varying layer depths. This was a limit to the model as there were only data for the areas where there were boreholes, so the layer depths are likely to be quite inaccurate. A similar method was used to create the surface elevation except that along with the elevations given at the boreholes locations, a grid of more elevations across the model (taken from map elevation contours), were imported. The ground surface elevations are therefore likely to be better represented than the deeper layers, but still not perfectly accurate.

As there is a large amount of abstraction from the lower aquifer, the wells themselves were entered into the model. The borehole cased and open depths were taken from the Well Head Protection Plans and the pumping rates were taken from data presented by the City Hydrogeologist (Appendix 7.3).

The two main rivers (Curlew Creek and Cedar Creek) were created in the model using polylines and the data collected previously for the ‘River’ input file.

Hydraulic conductivities, storage coefficients and recharge estimates were taken from the Brackish Well Report (Missimer International, 2001) and Leggette et al. (1994) and were altered slightly during calibration. Hydraulic conductivity of the confining layer was estimated and later lowered to 0.0005 m/d to prevent the upper cells drying out. An average evapotranspiration value was calculated from the USGS data set (USGS, 2010) but then lowered to prevent the cells from drying out. Initial water level for the surficial aquifer was set to 2.47m (a rough estimate of average water table provided by city officials). There was no data available on the water table depths in the surficial aquifer throughout the city.

There was little information to calibrate the model against. One piezometric contour map from the Comprehensice Plan (City of Dunedin, 2008) would have been useful, however the groundwater flow direction demonstrated (NW) was contradicted in the Well Head Protection Plan (SW). Again little information was gained in the city concerning this so the model was accepted once the upper sections had stopped drying out and the groundwater flows in the lower and upper aquifer looked reasonable. It must be stressed that this cannot be taken as an accurate representation of groundwater flow in Dunedin, but should hopefully provide aquifer properties that can be used well enough in the scoping model.

Although the head values are likely to be inaccurate, they are not thought to vary enough over the area of the city for this to be a major issue. Figure 19 shows the head contours for the lower aquifer.

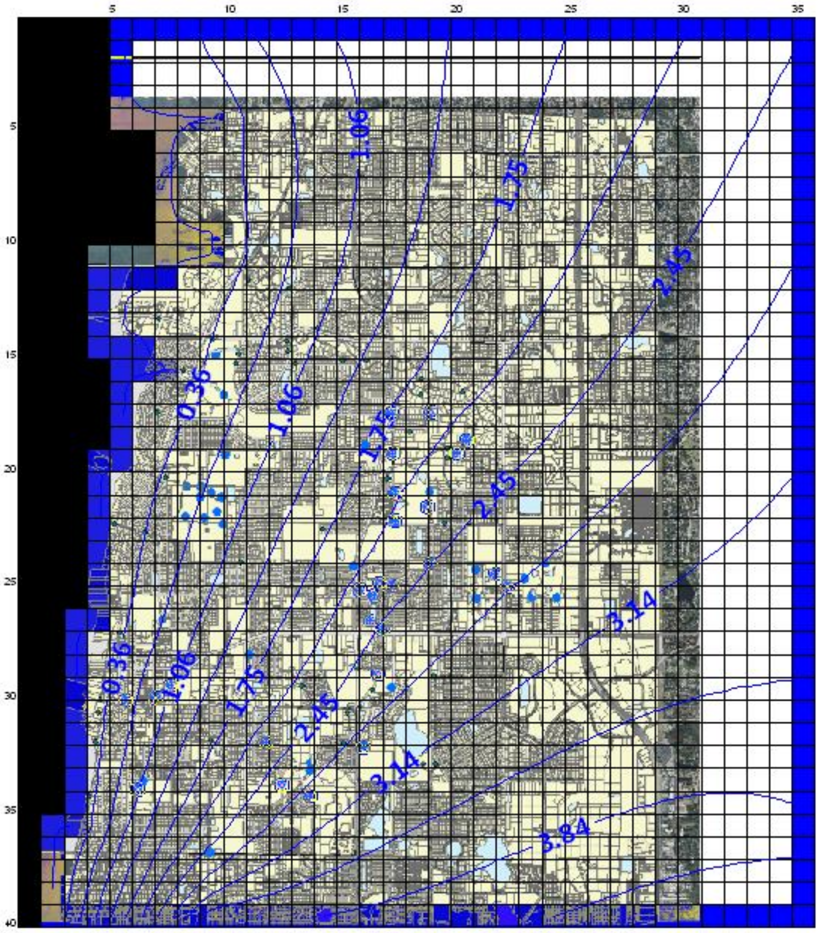


Figure 19 – MODFLOW model head contours for the Floridian aquifer.

The head values for the layers were exported and arranged into the CWB aquifer input file, as were the surface elevations and layer depths. The final aquifer properties used in MODFLOW were also input (Table 3).

Table 3 – Aquifer properties summary		
Layer	Property	Final input
1) Surficial aquifer	Kx, Ky, Kz	7, 7, 2 m/d
	Sy	0.35
	Evapotranspiration, ext_depth	0.0004 m/d, 1 m
	Recharge	0.0004 m/d
2) Confining layer	Kx, Ky, Kz	0, 0, 0.0005 m/d
	Ss, Sy	0 m^{-1}, 0
	Recharge	0.0004 m/d
3) Floridian Aquifer	Kx, Ky, Kz	127, 127, 10 m/d
	Ss	0.013 m^{-1}
	Recharge	0.0004 m/d

4.3.20 Current Water Management Options

Water management options for the current city management were input to the model as described below. Alternative options were also input to the same spreadsheets. Following this, 'Assignment' input files were created. These specify which of the management options are turned on or off for each minicluster. For certain management options there could be a variety of options e.g. for UB boreholes there are several different borehole types with different tank capacities. The option type is hence given as a number which relates to the option in the list specified (1 = entry at the top of the list, 2 = next entry below this).

Several different ‘Assignment’ files were created. The first is named ‘Dunedin_Base’ and represents the water management options that the city currently uses. The other Assignment files were created to investigate different water management options and test these against the different future scenarios (Section 5).

4.3.21 Unit Block scale options

The following unit block water management options were input as ‘not in use’: - UB raintank UB_WW (wastewater recycling), UB porous paving, UB swale, UB green roof, UB grey water irrigate.

Although there is evidence that rain barrels are beginning to be used, the numbers are not big enough (and the locations not known) to include them in the current water management options. Use of rain barrels will however be investigated.

4.3.22 UB septic tank

As there are still some small areas in the city that use septic tanks (locations outlined in Dunedin 2025 Comprehensive plan (City of Dunedin, 2008)), an input file specifying the typical dimensions and properties was created and the MCs in which they reside in, specified in the Dunedin_Base file. As there was no information available on the septic tanks specifications, the default values were used.

4.3.23 UB_borehole

It was discovered on the field visit that many residential properties and some others have boreholes in their gardens, which are used for irrigation. There was very little information available on the exact locations as although permits are now required, the legislation concerning this was not previously as strict. A map of borehole locations from 1983 was the

most up to date map that could be found (Appendix 13). As much of the area has now been linked up to the reclaimed system it is likely that many of the boreholes are no longer in use.

Local knowledge suggested that ‘non-reclaimed water’ residential unit blocks, especially those with large gardens, would likely use private wells for irrigation as most residents would not afford to use the amount of potable water required to frequently irrigate such a large space. Local knowledge also suggested that most private boreholes draw water from the surficial aquifer.

Although assigning boreholes in this way is only a very rough estimate, it seemed the most appropriate way with the data provided. Although well water is pumped and used directly, the model accepts inputs in the form of a tank and its capacity. The volume of water used by each borehole type was hence specified in this format. For the Dunedin_Base file, UB boreholes were assigned to all the ‘large house, medium garden, no reclaimed’ and ‘medium house, medium garden, no reclaimed’ UBs. The borehole tank capacities were given the same volume as the equivalent daily use of reclaimed water for the corresponding units blocks that are hooked up to the reclaimed network.

The model required updating so that there was an input to specify which aquifer layer the UB boreholes were pumping from (in this case the surficial layer 1).

4.3.24 Minicluster scale options

The following MC management options were set to ‘not in use’ for the Dunedin_Base model: - MC_SS (storm water harvesting), MC_WW (waste water recycling) and MC_filterstrip.

4.3.25 MC_Soakaway

The city storm water engineers outlined the current location of exfiltration pipes. There are 4 in total. These were split into two categories that were input: - main drainage for the minicluster and smaller drainage. The capacities were taken from the information provided by the storm water engineers. Infiltration coefficients were left at default values as this information was not available.

4.3.26 MC_PA

There were a few miniclusters that did have car parks made of pervious asphalt (Figure 20). These were pointed out by the storm water engineers. One type was specified, again leaving many of the default properties, and assigned to the appropriate MCs.

Figure 20 – Pervious asphalt

4.3.27 MC_Swale

Swales are used extensively throughout Dunedin to manage storm water runoff. There are no maps in existence that show their locations, and although they were seen and noted during

ground truthing exercises, a whole project would be needed to map them out. There were many along some of the larger roads and alongside some of the smaller roads (Figure 21). A few were also incorporated into residential grounds (mainly the apartments or larger scale residential UBs).

Three different types of swale were therefore defined. Information from storm water engineers stated that the city swales have a combined length of approximately 1320 lineal meters. Information was also provided on the typical slopes, depths, widths and drawdown times. Estimates were made of the split of the total lineal length of the swale between the three types defined. This was done by assigning the swales to MCs where there were know to be swales (from field work) and then distributing the remaining length evenly between the roads and apartments with grounds. Again, the uncertainty in this representation is fairly high but was the best method possible with the available data.

Figure 19 – Small roadside swale

4.3.28 Large scale options

Due to the water management practices in Dunedin, two of the three large scale options required much updating.

4.3.29 Large boreholes

As Dunedin's water supply comes solely from abstraction boreholes within the city, it is important to ensure that this water management option is representative. The current version of the model could not give a good enough representation, so this input file was rethought and updates suggested. These will be discussed fully in the Discussion (Section 8.2)

4.3.30 Large waste water recycling defaults

Due to the extensive recycled water network within Dunedin, again, this management option had to give a very good representation of this aspect of the water balance. The current model was not nearly adequate enough to do this. Inputs could not even be attempted with the old version. The reasons for this are discussed and suggestions for the new model made in the Discussion (Section 8.3).

4.3.31 Large storm water recycling

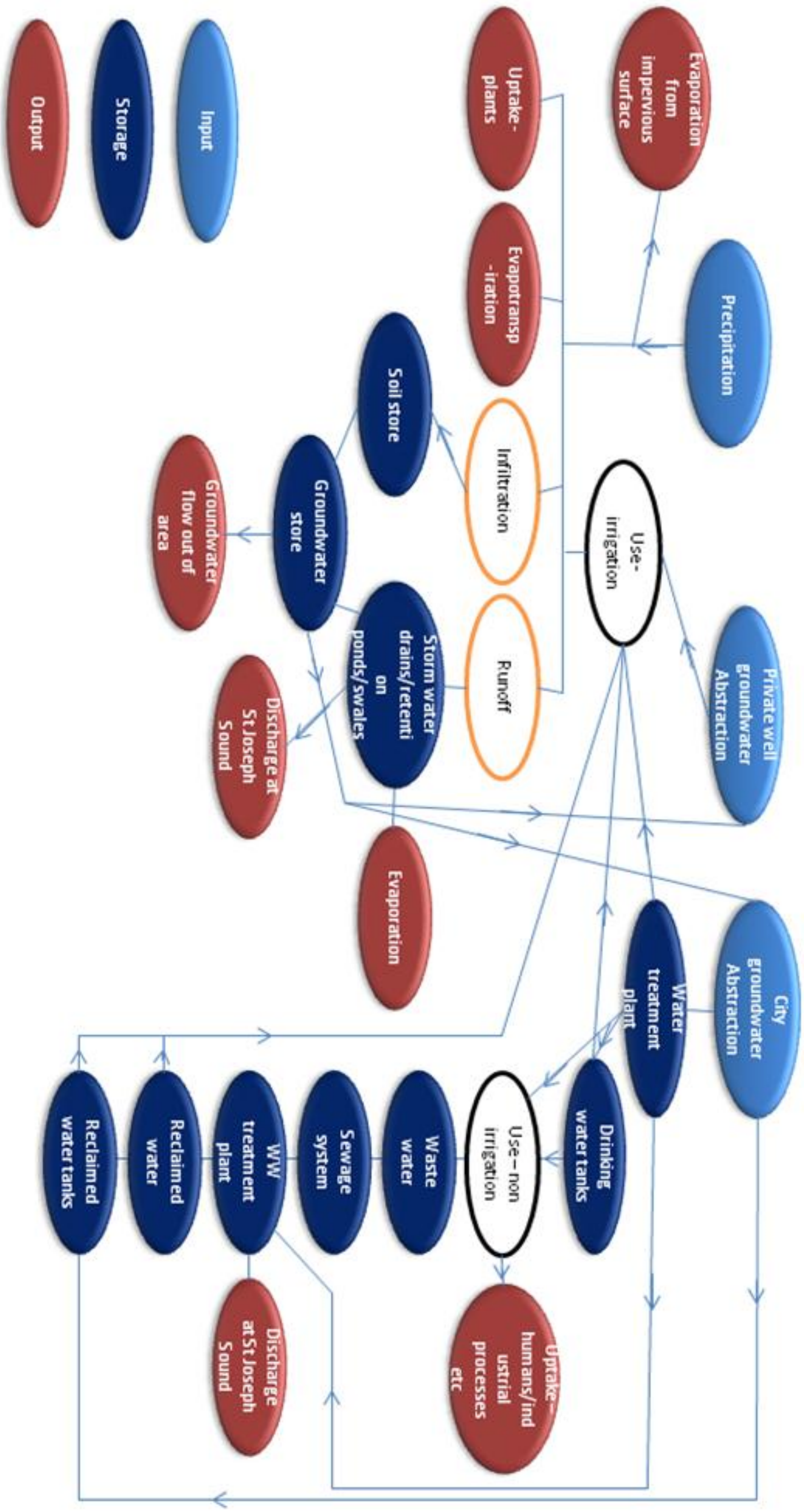
This is not a management option used in Dunedin. This input file was therefore left blank.

4.4 The Dunedin water balance

The flow diagram on the following page (figure 22) summarises the intricate linkages between the natural and man-made water systems in Dunedin, demonstrating the factors that the model will need to be able to represent.

The most up to data input files that are nearly ready to use in the new model can be found in Appendix 8.1. The arcGIS final base map for Dunedin with all miniclusters, subcatchments and surface water bodies (including their attribute tables) can be found in Appendix 8.2.

Figure 22 - The Dunedin water system. A summary of input, output and storage parameters and the linkages between.



5 Scenarios

After investigating water management options for the city in its current state, the same was carried out for investigating the water balance for possible future scenarios. CWB can be used as a tool to investigate a range of future scenarios designed by the user. As Dunedin is new to SWITCH there has not yet been time to formulate detailed scenarios, such as the ones developed by learning alliances in the other SWITCH cities. However, to give examples of CWBs potential here two future scenarios have been investigated: - 1) Climate change 2) Population increase, and input files created.

5.1 Climate Change

The IPCC (2007a) regional climate change predictions for North America were used to estimate the possible future climate. As this report gives predictions for such a large area the estimates are not likely to be very accurate for this particular area of Florida so the scenario will only give a look at the 'possible' future climate of Dunedin. A more detailed smaller scale study of climate change in Dunedin would be needed to give more realistic predictions and the model should not be held responsible for erroneous predictions.

Climate model simulations predict that for the Florida region there will actually be little change in precipitation in this century. However, there could be an annual average temperature increase of 0.3^{o}C by 2030. Evaporation figures were not presented in the report but using an estimated 7% increase in evapotranspiration potential for every 1 ^{0}C increase in temperature (IPCC, 2007b) there could be an increase in annual average evapotranspiration potential by 0.321%. These estimates are extremely hypothetical and do not take into account any seasonal climate change variations but can be used to demonstrate the potential of the CWB. For the first scenario the climate input file was therefore altered to show a daily

temperature increase from the original data of 0.3^{0}C and a daily PE increase of 0.321%. Precipitation remains the same (Appendix 9.1).

5.2 Population increase

Notes taken from the Water Treatment plant specified that the population of the city was not expected to increase much as it had reached build out, and hence that any additions to the well field in the future were solely to ensure good quality water, and limit the risks of hazards caused by over pumping, such as sinkholes and salt water intrusion. However, in the City of Dunedin's 2025 Comprehensive Plan (City of Dunedin, 2008), there is shown to be some expected population increase (Table 4).

Table 4

FUNCTIONAL POPULATION PROJECTIONS

	2010	2015	2020	2025
Permanent	38,626	38,973	39,214	39,381
Seasonal	2,933	2,960	2,978	2,991
Tourist	2,389	2,409	2,423	2,432
Functional	43,948	44,341	44,615	44,804

Source: Pinellas County MPO; Dunedin Planning & Development, 2007

As the predicted increase for tourists and seasonal occupants is below 60 people for each up to 2025, this has not been incorporated into the population increase scenario. This is because as the standard unit blocks for hotel and condo (where these population increases would have an effect) have higher occupancies, these relatively small increases could not be represented well with the current model unit blocks. However, to represent the total population increase to 2025, a new input file was created. The core inputs were kept exactly the same, but a number of residential miniclusters were added to areas where there had previously been POS.

A standard 'medium house, medium garden' was used with the same occupancy of 2.31as for the original model. It was decided that the new houses would be connected to the reclaimed system as it is likely that new housing developments in the city would be, as the city plans to increase the number of connections over time.

Therefore for this new scenario the model inputs that were altered can be summarised in the following list: -

- The arcGIS map spatial inputs (Appendix 9.2.2). Several POS MCs removed or made smaller and several 'medium house, medium garden, with reclaimed (UB_4)' MCs added to account for the estimated population increase of 856 by 2025.

  Calculation: 856 people/2.31 occupancy per house = 371 houses

  Average land area for this UB type = 745.4 m^2

  Total residential area to replace POS = (371 * 745.4) = 276543.4 m^2

- The MC assigns file updated to the new MCs, UBs and Subcatchments (Appendix 9.2.1).
- The MC Vertices file. The shapedump file must be re-run and the new list of vertices input (Appendix 9.2.1).

Minicluster numbers, 208, 86, 90 and 255 were changed from POS to UB_4 as this represented approximately the right amount of area. Everything else remained the same. The large scale WW recycling option assigns the waste water to subcatchment groups. The amount used in each subcatchment may alter figures but recycled waste water will still be distributed where required.

The increase in population would likely increase the occupancy of some of the other unit blocks e.g. shops and schools. However as not enough is known about how a demographic change would affect these specifically they were not considered for this scenario. There is scope here for further work.

6 Water Management Options for further investigation

It was originally planned that, once the model was calibrated, different management options would be investigated and compared. This was never fully achieve due to the model not being completed in time, however prior thought had gone into what management options may be investigated. A couple of example input files were also created for these new management options and have been included here for future use once the model is ready (Appendix 8.1).

6.1 Management Options 1 and 2 – inclusion of residential unit block raintanks

Conversations with the city's Sustainability Coordinator highlighted that several rain barrel workshops had taken place in the city, to educate local residents about the benefits of capturing rain water to use for irrigation and other uses such as washing gardening tools. During these sessions rain barrels (converted from disused plastic containers from the water plant and from the Coca Cola factory) of 55 gallons (0.208 m^3) were distributed to those who wanted one, for free. This was a fairly recent scheme and it was thought that not enough rain barrels were in use to make it worthwhile including them in the normal unit block management descriptions. However, as this is a management option that is obviously being initiated and encouraged, it would be an interesting option to investigate. The barrels are quite small compared to those that could be used, so it would also be worth investigating the effect of using larger rain tanks.

In the UB_raintank input file, the tank specifications were outlined (keeping cost and energy parameters with their default values as these weren't being investigated). The option was to be tested for residential use. A new assignments file '**Option1**' was therefore created which assigned these raintanks to all the residential unit blocks (keeping all other management options the same). '**Option 2'** was then created with the larger rain tanks of 2 m^3 assigned to the same unit blocks (this size was chosen as it had been used in the Birmingham model). The

raintanks were only used for irrigation but it should be noted that CWB allows raintank water to be used for indoor water such as toilet water, and other options (with treatment). If the city were keen to look into this, these options could be investigated. The cost and energy considerations would be useful here as installation and energy would obviously play a large part in the decision process of whether or not this management option is a more sustainable. If raintanks were used for toilet water, for example, a pump may be required to lift water high enough to create the required pressure. First flush consideration would also apply.

6.2 Management Option 3 – discontinuing UB septic tank usage

As the city would like to eventually have all customers within the city, including enclaves, hooked up to the waste water system, CWB could be used to investigate the effects this will have on the water balance. Without the septic tanks there is more control and easier monitoring over possible contamination of the aquifer that is of high importance for the city supply. It would be interesting however, to view the other sustainability indicators to see if this would have a good effect overall for the sustainability of the city water system.

As this management option requires the removal of septic tanks, the UB Septic tank input file does not need to be changed. The new assignment file '**Option 3**' was created to remove the UB septic tank assignments.

6.3 Management Option 4 – expanding the large WW recycling

Currently approximately 1 in 4 water customers are also supplied with reclaimed water. There are plans to get more and more people using this recycled water system so this would be an obvious management option to investigate. Option 4 was not however created as the model updates for the large scale waste water recycling inputs was still being updated at the time of this write up. The investigation of this idea may also need more data concerning the

expansion ideas as it is assumed more storage tanks would be needed. The location and dimensions of these as well as information about the total volume that could be created by the waste water plant may be needed, before all the miniclusters in the city could be assigned to the new storage tanks.

These were the management options that were planned on being investigated, however it was also thought that once the model had been calibrated several other options would be trialled and investigated simply using the CWB interface.

6.4 Water Management Options in Response to Future Scenarios

The above water management options were going to be investigated with the current model but also with the future scenario models. The climate change estimations show that there could be higher rates of evaporation and therefore less recharge to the aquifer. The population increase estimates also show that there could be a higher demand on the resources. Building housing units over what was previously POS is also likely to decrease recharge in these areas, putting additional pressure on the resource.

Management options such as increased used of the large scale waste water recycling and use of raintanks could lower the pressures on the potable water and would definitely be worth investigating. Another option would be to investigate expansion of the well field. The city is currently trying to pump at lower rates than previously, to prevent water quality issues and sinkhole hazards. They are however considering increasing the amount of wells. CWB could not be used to look in detail at the hydrogeological effects but could be used to look at the large scale water balance implications.

7 Results

7.1 Model Calibration

Due to the adaptations to the model not being implemented in time, the model could not be used for Dunedin. However, data had been collected and processed that would have aided in the calibration of the model and these are outlined here.

7.1.1 Waste water

Data from the sewage lift stations had been collected from the waste water treatment plant (Appendix 3.1). This shows inflow to each lift station. The subcatchments had been created around the areas services by these lift stations so this information was perfect for assisting in calibration of the model, as volumes of calculated waste water flow out of subcatchment areas could be compared to actual values over the years 2008 and 2009. As several of the subcatchment groups included several lift stations, the ultimate lift station that all other flows lead into needs to be the one used for the waste water flow output for the subcatchment. Table 5 shows which lift stations must be used for each subcatchment.

Table 5 – lift stations for calibration	
Subcatchment	List station to be used in total waste water output calibration
1	15 *(-22)
2	12 + 12a
3	9 + 7
4	23
5	20
6	30
7	5
8	21
9	8
10	11
11	6 + 25
12	38
13	2 + 3
14	10
15	Inflow to WW treatment plant

Daily Monitoring Reports (DMR) from the waste water treatment plant showing total inflow of waste water to the plant each day could also be compared to the simulated model results of waste water leaving the system.

A few things are worth noting with regards to calibration using the waste water data: -

1) *Honeymoon Island was not included in the model. Therefore the waste water from lift station 22 must not be used and must be deducted from the total waste water inflow to the waste water treatment plant (plus any estimated leakage there may have been from that amount of water. This leakage would still contribute to aquifer recharge so may have to be accounted for by raising the leakage factor for the other sewage pipes).

2) The leakage out of the sewage pipes is taken into account in the model; however data analysis has shown that there is a definite relationship between the amount of rainfall and the flow through the sewage pipes. As the system is not a combined system and is not connected to the storm water system, the increase must come from pipe infiltration. The model would benefit from allowing pipe infiltration, but for the time being the calibrator must take into account that there is likely to be more waste water flow out of each subcatchment in times of heavy rainfall. An exact proportion cannot be placed on this relationship with the current dataset, however a small investigation has been undertaken and it has been found that lift station 8 appears most prone to this phenomenon (Appendix 3.4). Without a working model the magnitude of the affect on the system cannot be investigated but there is scope here for future work.

3) The minicluster representing the Coca Cola factory lies within subcatchment 15 and its waste water is therefore accounted for by the ultimate pump station within this subcatchment. However, it is only the sanitary sewage that is connected to the city

sewage system. The factory has its own activated sludge waste water treatment plant which most recent estimates show has an annual average daily discharge 0.2542 MGD (but it has a permitted discharge of 0.45 MGD) (DEP, 2008). As the model has no way of differentiating between waste water outputs from different places, this average must be added to the total daily discharge figure, so this can be compared with the model outputs. It must be taken into account that this is only an average figure and not as accurate as the data provided from the waste water treatment plant on their discharges. It must also be taken into account when investigating management options that this volume of waste water cannot be used for reclaimed water (as the system currently stands).

4) There is another waste water treatment plant, Utilities Inc. This only services a small area in the East of Dunedin. The majority of this area was left out of the model area so that problems with the water balance were not encountered. However, there is a very small area within the model city limits which is serviced by this other treatment plant. It is hoped that as it only accounts for the waste water from such a relatively small section that the effects will not be too great. This could be investigated further, once the model is working.

5) The Greenbriars area to the SE of the city is not serviced by the waste water treatment plant and relies on septic tanks. This area was not included in the model area as it was know from the early stages that this area was not linked up to the water networks in Dunedin, so this should not be an issue during calibration.

7.1.2 Reclaimed Water

The DMR reports also showed the volume of reclaimed water created each day, so this could be compared to the simulated volumes for this part of the water balance. The model outputs

the results for the different spatial scales so the reclaimed water could be checked at the different levels i.e. as the volume of reclaimed water is defined by the user at the large scale, the results of how much would be used for the different unit blocks could be compared to real data provided by the city (Appendix 10.1). Reclaimed water users are permitted a certain amount of reclaimed water dependent on acreage (0.8inches/d/acre). If they use more than the permitted amount they must pay a surcharge. This puts a good estimate on the amount of water that each unit block (that has reclaimed water) uses. The outputs from the model could therefore be compared quite easily. Appendix 10.1 also shows reclaimed usage data for individual addresses. This could be put to good use. It could be investigated if the 'tigger to irrigate' function in the UB_default input gives the right amount of irrigation.

Unfortunately no information could be found on the volumes of storm water leaving the city so this cannot be used for calibration.

7.1.3 Water supply

When the model updates have been added, the large scale borehole management option will account for all the supply water going into the Dunedin system. This is user defined and based on figures from the water treatment plant. The volumes of water being supplied and used can be checked in the smaller scale outputs once the model has been run, to make sure the usage inputs are representative. If not, they can be altered accordingly and any updates to the spatial representation made.

7.2 Basic Recharge Calculations and resource limitations

Quick calculations for recharge were attempted, when it was found the model would not be ready in time. A Penman-Grindley code was written in visual basic (Appendix 11.1.) and precipitation and PE values used, along with soil coefficients (root constant and permanent wilt point). The runoff coefficient was set to 0 so the no runoff would occur. Two sets of calculations were carried out, one for pervious areas where irrigation was also occurring and one where irrigation was not occurring.

A basic figure for estimated irrigation of 2.9mm (0.8 inches) per day was taken from the reclaimed water guidelines and added to the precipitation value for each day. This is not very accurate but was the best method available at short notice with the current data set.

The spatial inputs that had been prepared for CWB were used to estimate the total pervious area in the city, and the total irrigated pervious area. The irrigated area was then multiplied by the irrigation recharge value to get a daily recharge volume. The non- irrigated pervious area was multiplied by the standard recharge value, and the two volumes added together, to give the total average daily recharge volume (Appendix 11.2).

The reason for the recharge calculations was to investigate the total usable water resource for the city and to see how much more water it is feasible for the city to pump if they expand the well field, putting some limitations on this resource. However, when the recharge volume was compared to the total volume of water pumped from the aquifer (2008 data set), with these calculations there does not appear to be enough water recharging the system (20921.3 m^3/d recharge compared to 18176.8 m^3/d abstracted).

The difference between the two figures is not large and this cannot be correct firstly because the catchment area of the boreholes and extent of pumping is much less than the city area,

according to the Well Head Protection Plans (Villalpando, 2008). This suggests that the city does not abstract close to their recharge limit. As far as we know though there are no major flows into the area and most groundwater replenishment occurs largely through precipitation and recharge directly over the city area. The abstraction radii of the boreholes should give the area over which enough recharge occurs for abstraction. This calculation has not been attempted as by looking at the recharge figure produced for the whole city area it is obvious that this method of calculation would not give sufficient recharge over this much smaller area (even when runoff is set to 0).

The calculations are therefore disturbing as this type of soil moisture balance calculation of recharge does not appear to work well for the city. It is likely that a lot of the recharge happens in storm events and more bypass flow occurs, and that the Penman-Grindley method cannot calculate this. If this is the case then it is possible that the similar (but more detailed) methods used in CWB may also not allow for enough recharge. This will have to be investigated with the working model.

8 Discussion

8.1 Model Issues and Updates

Below is a summary of the changes that have been or are required for the model: -

- A more user friendly input file. The separate text and csv files that were not labelled with titles have been transferred to well laid out worksheets within one spreadsheet.
- Clearer instructions for users on the order in which the MCs need to be arranged in arcGIS, in order for correct vertex outputs using shapedump. The model aims to be user friendly and this would speed up the modelling process.
- The water usage assignments in the UB split usage sections need to include an option that allows water to simply be used up e.g. for industries that use water for products.
- An allowance for sewer infiltration as well as exfiltration is required, so that water leaking into the pipes in times of heavy rainfall, will not be mistaken for the actual waste water from the miniclusters, upsetting the water balance.
- The soil types input file would be better if it accepted properties from one type of soil definitions e.g. USGS. As it currently stands, the particular properties for the soil types are not easy to find and many properties have to be estimated.
- It was decided that for Dunedin, the climate input file was fine as it is. However, a Theissen polygon type approach may be better for representing rainfall over larger cities that have varying rainfall.
- Changes were planned to alter the river slope input from a gradient to a 'top and bottom of segment height', so that the model could relate the gradient to the length of a segment. The work on this aspect is ongoing because a method of input needs to be

considered for river segments that do not travel in a straight line between their highest and lowest heights. The gradient must be related to the entire length of the segments and the vertices which represent the shape.

- The pond inputs file needs to be updated. The 'permanent water volume' input doesn't make sense as this would only allow one volume of water in the pond. Instead an initial height input is required, which the model can relate to the pond vertices to calculate a volume of water. The ponds could then fill up in heavy storm events or dry out etc. The maximum water height can be used to limit the pond depth and cause recharge or runoff if the water spills over.

- The 'aquifer' input file was improved so that the model could accept more than one layer. Originally the model could only work with a simple one layer unconfined aquifer. Updates were also made so that constant head boundaries could be assigned and a give a representation of groundwater flow out of the area, rather than only allowing water to leave the groundwater through surface water expression and drainage. It was especially important to get the aquifer input file right for Dunedin, as no water is imported and all potable water is sourced from the aquifer in the city area.

- The UB_borehole water management option needed updating to match the new aquifer input file. An input is required to allow the user to specify which layer the borehole is pumping from.

The two main other input files that require drastic alteration for Dunedin are the large scale water management options for borehole abstraction and waste water recycling.

8.2 Large borehole management option

Obviously this input file required altering so that the user could define which aquifer layer the large boreholes are abstracting from. Based on the system in Dunedin, other changes that were required also came to light. The file needed updating from the original so that the borehole water could be used to supply all split usages, rather than just usage 1 (toilet), garden and POS irrigation.

The model cannot simulate the water being pumped to one central location and then distributed (as it is in Dunedin after it has been treated at the water treatment plant). Again the model accepts tank sizes, which show the volume of water that is pumped each day. The water from each tank must then be assigned to a set of miniclusters that it is supplying. However, the model does require the x and y coordinated of the boreholes so a tank must be assigned to each borehole.

In Dunedin there are 4 2MG tanks that hold drinking water, however as these could not represent the borehole locations and pumping they could not be included. Instead with the new model the borehole locations will have to be entered along with a hypothetical tank volume that can represent the average volume of water pumped each day. The water will then have to be split between the miniclusters. As all miniclusters are in fact supplied water which comes from the water treatment plant, these assignments will have to be best guesses depending on how much water each borehole pumps (as this varies), and how much the water demand is for each group of miniclusters. This will have to be a rough estimate and could be altered during the calibration process. The miniclusters can be assigned to each borehole in groups (which are defined in an earlier input file). It is unclear if more than one borehole can supply the same minicluster in the model. If this is the case then all the boreholes could be assigned to supply 'group1' which includes all the miniclusters. The model could then

distribute the water as needed and defined by each unit block usage default. If this cannot be done then 26 groups of different miniclusters would have to created and each assigned to one of the 26 boreholes.

Another point to consider is, at what point do the ‘tanks’ get filled with water? It is not clear from the instruction manual how the process works in the daily time step. Each unit block within a mini cluster has a volume of water that is requires for supply. As the ‘demand suppliable’ input has been set to 100% there must be enough water to supply the demand. However, each day, after the demand has been met there may be a surplus of water. The question is, does this water simply remain in the ‘tank’ and get added to the next days water before supply occurs? If so does the tank overflow the next day when borehole water supplies it? And, does this water become removed from the system or become runoff/recharge? If this is the case then the model is not representative because in the real system there are no tanks at the borehole locations and no water escaping out of pipes to recharge at these locations. The model may need altering here or at least made clearer to the user.

There is another problem with representing the Dunedin system. In times of low demand, borehole water can be pumped straight to the reclaimed water tanks to top them up. This water would therefore bypass the main route completely, ending up with the recycled waste water. Little is known of the volumes of water that are used for this purpose and it would be difficult to model. Perhaps it would not make a large different to the total water balance if it only happens on rare occasions but this just demonstrates how individual water management systems for specific cities can be hard to represent within the limits of the model.

Although this aspect of the model has been investigated and updated by looking at the water flow aspects, it will also be very important to get this section of the model working well for studies that look in more depth at the water quality sustainability indicators.

8.3 Large waste water recycling management option

This input file works similarly to the boreholes in that it accepts volumes of waste water recycling by specifying a tank size. In the case of Dunedin the waste water is pumped to the waste water treatment plant and then some of the recycled water gets pumped to storage tanks before supplying customers. These tanks were therefore used. As much of the recycled water gets pumped straight from the waste water treatment plant to the customer, another hypothetical tank had to be created to represent the large volume for recycled water from the treatment plant. The same issues as mentioned above with the boreholes, with regard to the order in which the water is supplying the tanks and being used by the customer, are apparent here too.

As waste water from all the miniclusters within the city has the potential of being recycled at the waste water plant, all of them would have to be assigned to one of the tanks as 'tanks receiving from, miniclusters'. This would have to be estimated by splitting the city into equal areas and assigning each area group of miniclusters to one of the tanks. 5 new minicluster groups would therefore have to be created. This may not balance up correctly and this would have been investigated had the model been ready. All the miniclusters that are known to use reclaimed water would then have to be split between the tanks and input at 'supplied by tanks' (and additional 5 minicluster groups created).

There are many things to consider here. Most importantly, that the waste water recycling system in Dunedin is unique and complex (but there may be equally complex systems elsewhere so this is a good test for the model). Although the reclaimed system is large, not all of the city waste water gets recycled to reclaimed water that will be used again within the city. As mentioned in section 3.4 there is still an amount of treated waste water that gets

discharged to St Joseph Sound. The amount is dependent on the demand for reclaimed water at the time.

The reclaimed water can only be used for irrigation and this amount is defined by the areas of land to be irrigated and the trigger to irrigate value in the UB_default input file. However, as the model stands, there will always be a certain amount of recycled waste water produced and this is dependent on the tank volume, not the demand. In real life, if less reclaimed water is required the tanks won't be continuously refilled and more water will be discharge to the sea. Again though, more information is needed on how the model reacts to a surplus of water in situations where the tanks 'overfill' and the timing of this. If the excess amount of water simply disappears from the system, this may create a water balance which works, as although in reality this water would not be pumped to the tanks in the first place if it wasn't needed, the water would instead leave the system by being discharged to the Sound.

8.4 Other considerations concerning input data

The AMR data used for defining the UB water usages came from one example per unit block. Ideally averages would have been used but as mentioned there was not the time for the collection of more meter data. It was decided that the data should be used anyway in the first run of the model. However, if the balance is a long way off it would be best to change to standard usage values from literature. These are however, hard to relate to a large range of different unit block types. Only by running the model and looking and studying the outputs more closely could it be certain which method is more representative for Dunedin.

As mentioned there needs to be an input parameter which allows for water to be transferred to a unit block and then simply used. The main example for this is the Coca-Cola factory. The

input files that have been created (Appendix 8.1) have several gaps where the model requires updates. The usage for the industry UB in the UB_defaults has been left blank for this reason. It was found in the latter stages of this project that not only does the Coca-Cola factory use water from the city supply system; it also has its own RO treatment facility and onsite borehole/s. Little is known of the specifics but this needs to be included in the model. Another borehole will have to be added in the management options that just supplies the factory. Assuming that the borehole pumps enough water for it to be worthwhile having a separate RO facility on site, the borehole also needs including in the groundwater model, used to output aquifer properties.

Part of the test of the model was to see if the data required could be accessed with ease from different cities. A large amount of data was uncovered from Dunedin showing that it can be done, even in a short space of time if good records exist and people are willing to cooperate. This work has also highlighted however, that in depth knowledge of all of the city water aspects is required by the user as it is not simply a case of finding numbers, putting them into the model and pressing ‘go’. Although the model is supposed to be ‘simple’ it includes such a vast dataset and very complex interactions, the modeller must be able to understand to get the best results.

8.5 Default values and estimations

More data was collected than expected on the visits to Dunedin, making a good set of input data for the model. However, as the dataset for the model is so large and varied, there were bound to be several pieces of information which could not be found. In most of these cases, the default values that were used in the Birmingham model have been left as the input values. For some parameters, estimations have been made. Table 6 summarises all the data inputs

that have not been taken or calculated from real datasets. It should be noted that some of the input values based on data collected or observations e.g. proportion irrigated, are still estimates but these are not included in the table 6.

Table 6 – defaults and estimates from defaults			
Input file	Input parameter	Default or estimate	Notes
UB_default	Roof Initial Loss Paved Initial Loss Trigger to Irrigate	Default	
MC_default	Sewer exfiltration Infiltration recession coefficient Woods intercept Woods evapotranspiration Road initial loss Recharge index Infiltration store index	Default	
Soil type	All input parameters except drain factor	Estimates	This input file may be update so that more standardised soil data is accepted as inputs. Estimates for soil capacities and drain max. Were made
	Drain factor	Default	According to Last, this value is very sensitive
UB_Septic tank, MC_soakaway	Infiltration coefficient, infiltration index	Default	
MC_PA	Effective depth, seepage rate, infiltration proportions.	Default	
MC_swale	Recharge and infiltration idex	Default	

8.6 Model sensitivity testing

It had been the original plant to test the sensitivity of the working model to several of the input parameters. Obviously this is not possible. It would have been the plan to investigate

certain parameters based on the model output results as the areas where the model doesn't not appear to represent well, would have been identified at this point. However, without a working model it is difficult to pin point the areas that would have most benefited from a sensitivity analysis. The list of default values and large estimates above would be a good place to start. Last stresses that in the Birmingham model, the input for 'drainage factor' was extremely sensitive and small changes in this input value had big effects on the model outputs. This would definitely have been worth investigating for the Dunedin model to see if there were similar effects. Sensitivity testing for the default values would also definitely have been worthwhile. This would have shown if using default values was an acceptable method. If small changes in these input values make large differences to the model outputs, then it would be important to find accurate data for these inputs that is specific to the particular city. This observation could be specified in the user manual to inform future modellers.

9 Recommendations and Further Work

The obvious next step is for the improvements to the model to be made. This work is currently ongoing. Almost all of the input files have been created as part of this project and are ready and waiting to be used in the model. A couple of blanks have been left where the data for Dunedin would not work and the files will be updated. This work will have to be continued once the model is complete, but the requirements are minimal. The main work will be calibrating the model.

Once the model has been successfully used and calibrated for the current management practice in Dunedin, the different water management options can be investigated and the model used to look at the water balance for future scenarios. All the background research, planning and creation of input files has been completed here. There has been an explanation of the uncertainties, and areas that may cause issues in the model runs have been predicted and discussed. Further work will hopefully use all the information presented here to go and successfully model the city. It was a great shame that this could not be completed for this project.

Different scenarios and management options to the ones described here could then be investigated as the next modeller sees fit. The next step would then be to take the study further and use the other sustainability indicators included in the model. For the purposes of this study the water flow sustainability indicators were the only ones that were going to be used. Therefore any input parameters concerning contaminants and quality, or energy and cost were either left blank or left as the default values. Some quality data can be found alongside the data collected in Dunedin for this study (Appendices), but this was not studied and more information and data may be required. Very little data on energy and cost was collected so this may require another field visit. With the extensive reclaimed water system in

Dunedin, it would be particularly interesting to investigate the water quality issues associated with this i.e. the balance of TDS through the system and whether there is a build up of dissolved solids in the water as it is recycled.

10 Conclusion

Due to the model not being completed on time, several of the original project aims could not be fully achieved. However, the first aim of the project has been satisfied on a grand scale. The unique and complex water management systems in Dunedin have been a good test of the CWB model. The aquifer input file has already been much improved and several areas of the model are in the process of being updated, the main ones being the large borehole and large waste water recycling input parameters (see Discussion for full list of updates).

Future scenarios will likely show that there is more pressure on the water resources either due to an increased demand or a decreased supply due to less recharge to the aquifer, or both. This extent of the impact can only be quantified once the model has been used. Basic recharge calculations for the city using a Penman-Grindley model did not give adequate results to investigate the limits on the water resources in the city any further.

Further work is required to update the model and carry out the modelling process based on the input research and input files presented in this project. Although the model could not be used, this project has still been extremely worthwhile. Due to the large amount of data that was collected for Dunedin and the knowledge gained of the complex water management in the city, vast improvements have been and will be made to CWB.

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Occupancy rate sources

Industry (Coca-cola factory) - http://www.manta.com/c/mn8xk4p/coca-cola-co

Hotel (Holiday Inn Express) - Holiday Inn Express (visit)

Hospital – www.hospitaldata.com

Office (Planning and development and the Sherriff's Office)– www.dunedingov.com

High school/Elementary school – http://www.americantowns.com/fl/dunedin-infrmation#data

Nursing homes – http://www.city-data.com/zips/34698.html