TANK PADDOCK

A comparison between traditional and Water Sensitive Urban Design approaches

By Peter Coombes and George Kuczera
University of Newcastle

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Abstract

A study has been undertaken to compare the performance of traditional and WSUD developments for the Tank Paddock site. Construction costs and performance of the different stormwater management approaches has been evaluated.

The WSUD scenario revealed significantly reduced stormwater peak and volumetric discharges. A direct benefit of this result is considerable reduction in construction costs (53%). Indirect benefits of this result include reduced potential for erosion damage, safer roads during large storm events and reduced contaminant transport to Hexham swamp.

Although this study uses approximate costs for all stormwater related construction activities, the comparative evidence presents a compelling prima facie case for implementation of the WSUD option.

1.0 Introduction

The Tank Paddock drains to Hexham Wetland and is located approximately one kilometre north of Minmi on the eastern side of Lenaghan's Drive. It is proposed that approximately 30 Ha of the paddock is developed as a rural residential subdivision.

Urbanisation of the Tank Paddock is expected to have damaging environmental impact on the Hexham Wetlands that result from:

- Removal of vegetation
- Increases in impervious areas
- Increases in peak discharges
- Increases in discharge volumes
- Increased sediment loads
- Increased nutrient loads.

The local Council has agreed to consider the subdivision proposal if the developer demonstrates that he can mitigate the development effects on the Hexham Wetland.

Two different solutions are proposed. One solution is a traditional case that uses kerb and gutters, pipes, pits and detention basins. The other is a Water Sensitive Urban Design (WSUD) case that will use rainwater tanks, contour banks, vegetated filter strips, grass swales and some traditional measures.

A subdivision design (Figure 1) has been developed for use in a comparison between WSUD and traditional approaches to stormwater drainage design.

1.1 General Guidelines

The impervious areas on each allotment have been limited to 400 m^2, native vegetation is retained, native fauna is protected by retaining bio-diversity corridor and narrow road pavements (7m wide for traditional case and 5m wide for WSUD case) are used to reduce stormwater runoff from the proposed development.

The design criteria includes:

1. The total post development site runoff for storm events from the 5-year ARI up to the 100-year ARI, for all storm durations, are controlled to be no greater than predevelopment site runoff for the corresponding ARI event.
2. The 5 year ARI storm event is used for the minor design and the 100 year ARI storm event is used for the major design
3. Drainage works are designed in accordance with:
   - Australian Rainfall and Runoff, Institution of Engineers (1987).
   - Managing Urban Stormwater: soils and construction, Department of Housing (1998)
   - Managing Urban Stormwater: treatment techniques, EPA (1997)

1.2 Data

The following data was used for the traditional and WSUD scenarios:

- All roof areas are 220 m^2 and impervious driveway/paths areas will be 180 m^2.
- Soil types are a sandy loam (hydraulic conductivity = 5 x 10^{-5} m/s, depth = 0.5 m) overlying a leached clay (hydraulic conductivity = 5 x 10^{-7} m/s)
- The site predevelopment vegetation is native open forest in all areas except for the ridge tops, which has prairie grasses. For predevelopment modeling purposes the site has 90% native open forest and 10% prairie grass.
- The climate zone is Newcastle.
- No construction activities or stormwater drainage measures are allowed within the bio-diversity corridor
- Only three outfall locations to the bio-diversity corridor are used
- The subdivision consists of 41 allotments with an average area of over 3500 m^2 per allotment (see Figure 1).
- The development uses a minor/major stormwater management approach
- All major (up to the 100 year ARI storm event) stormwater runoff is to be contained within road reserves or drainage easements.

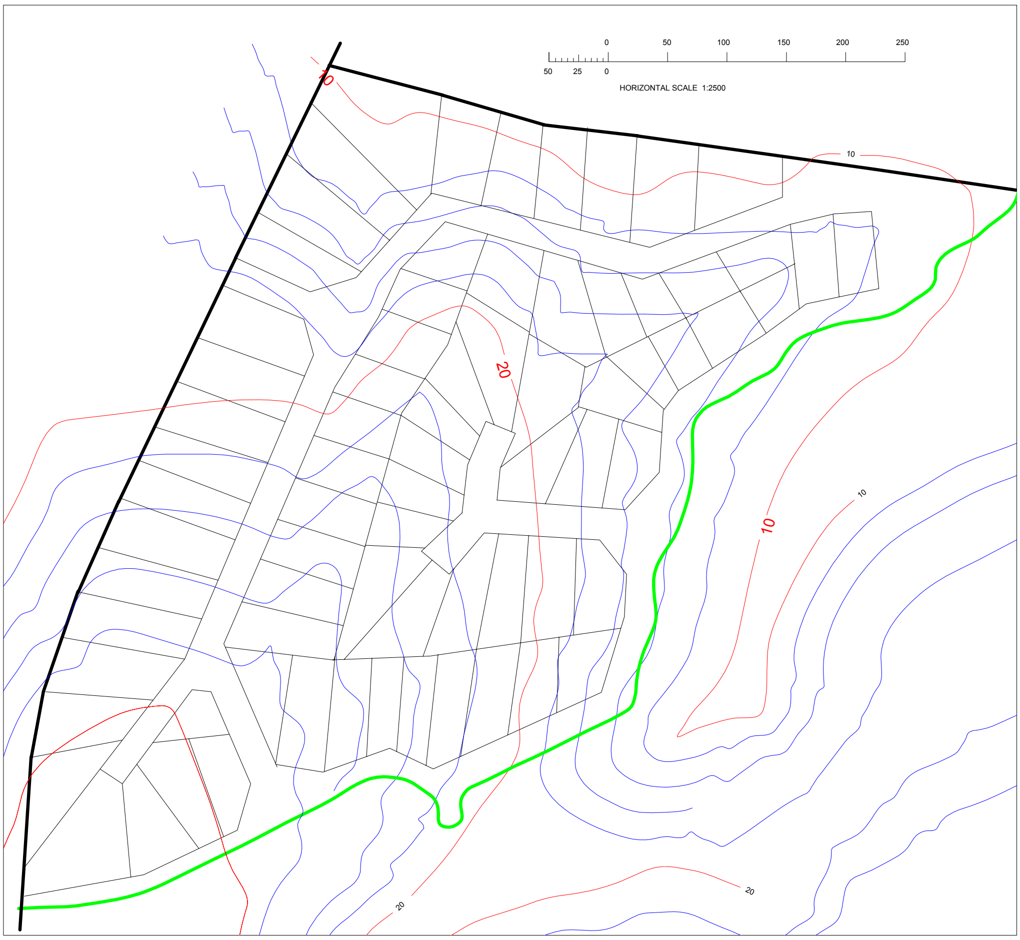

Figure 1: Part of Tank Paddock subdivision

2.0 Natural catchment

The expected stormwater peak discharges from the subdivision area (Figure 1) prior to development has been evaluated (Table 1). Although three discharge points from the area were used that corresponded to natural flow paths the majority of stormwater runoff from the site is considered to be overland flow.

Model parameters typical to the ILSAX computer program have been used in the analysis. Soil type 2 (saturated infiltration rate of 13 mm/hr) with an antecedent moisture condition 3 (wet) has been used. Pervious area depression storage of 5 mm and pervious sheetflow Manning's n of 0.2 is also used.

The peak discharges for the different ARI storm events (Table 1) are used as guideline values for the traditional and WSUD approaches to stormwater management.

Table 1: Natural catchment peak discharges

ARI (years)	Q (m3/s)
2	0.116
5	0.774
10	1.302
20	2.115
50	3.168
100	4.055

3.0 Traditional catchment

The traditional approach has been developed in accordance with the requirements of Australian Rainfall and Runoff, Institution of Engineers (1987) and the requirements listed above. The stormwater drainage design concept is shown in Figure 2.

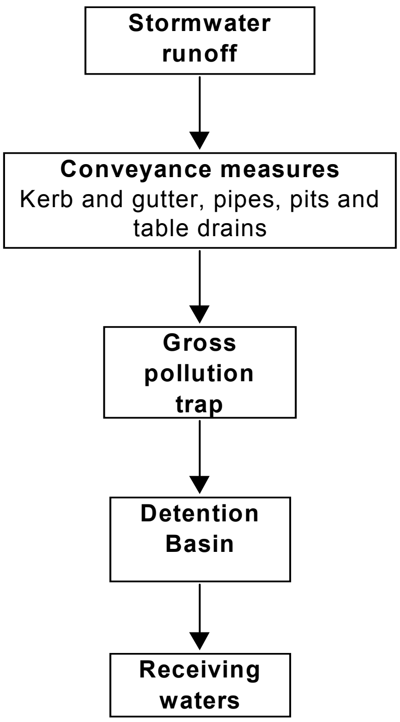

Figure 2: Traditional stormwater design concept

The traditional stormwater drainage design was modeled using the computer program WUFS (Water Urban Flow Simulator) developed by Kuczera and Hardy (1999) from the University of Newcastle. The model is shown in Figure 3. Nodes denoted as G are kerb inlet pits, S are sag pits, T is a detention basin, D is a gross pollutant trap and X refers to an outlet.

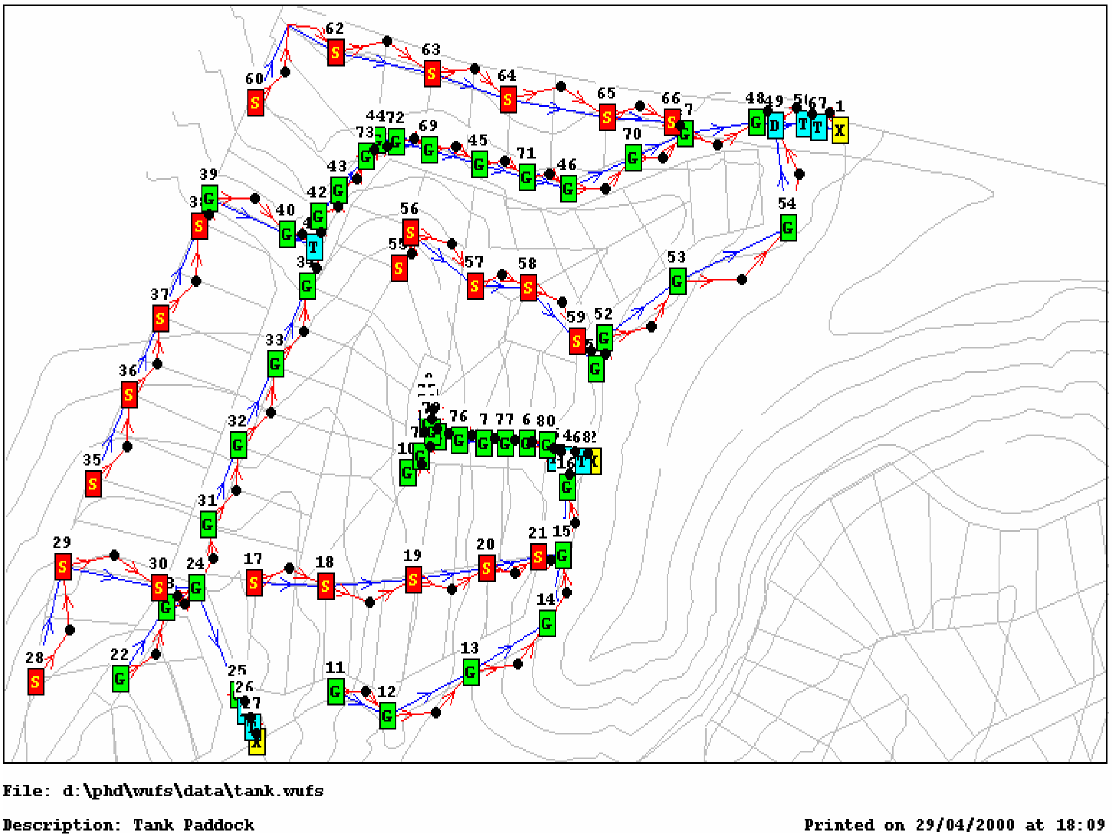

Figure 3: Traditional drainage model

In addition to the parameters used for the natural catchment analysis impervious depression storage of 1 mm is used. Pit blockage factors of 0.8 and 0.5 were used for kerb entry pits and sag pits respectively. The peak stormwater discharges resulting from different ARI storm events in the traditional design are shown in Table 2.

Difficulty was experienced in meeting the guideline values (Table 1) for peak stormwater runoff. However, the result was obtained with the use of large cascading detention basins at two of the outlets and a single large detention basin at the remaining outlet.

Table 2: Traditional catchment peak discharges

ARI (years)	Q (m3/s)
2	0.184
5	0.785
10	1.407
20	2.075
50	2.947
100	3.83

Construction costs have been evaluated for elements in the subdivision that will be effected by either the traditional or the WSUD stormwater design using data provided by Newcastle City Council. The road cross-sections (Figure 4) has been designed to contain a major storm event (100 year ARI event) and bulk earthworks are assumed to cost $30 per cubic metre.

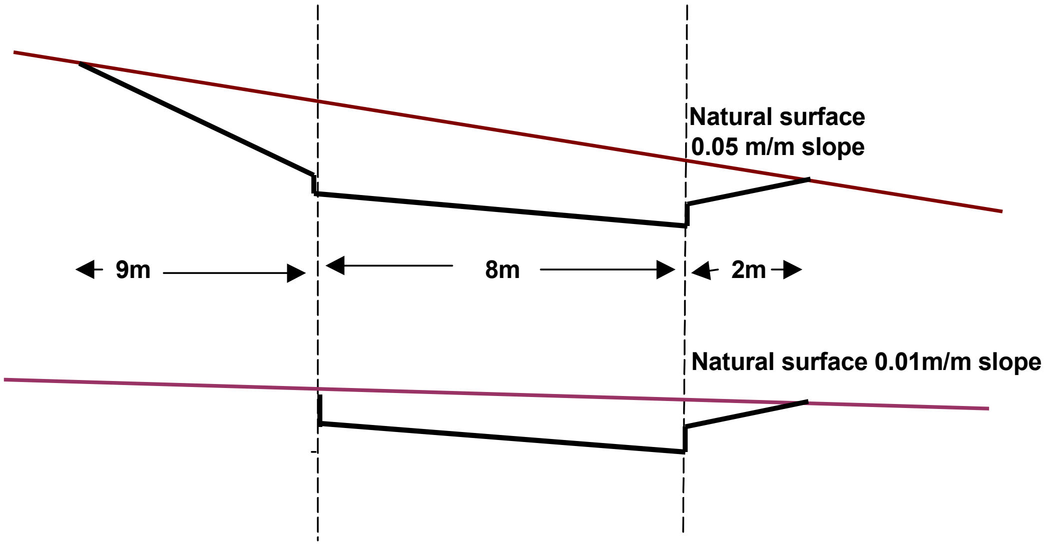

Figure 4: Road cross-sections used for bulk earthworks calculations

The road bulk earthworks calculations were divided into two typical cross-sections (Figure 4) in order to estimate varying site conditions. One thousand metres of road cross-section is assumed to have a natural surface cross fall of 0.01 m/m and the remaining 1100 m of road cross-section is assumed to have a natural surface cross fall of 0.05 m/m.

The road is constructed using a 200-mm thick gravel base, a 15-mm thick AC wearing course, rollover kerb on the high side and kerb and gutter on the low side. Detention basins are assumed to cost $30 per cubic metre. Table drains are 2 m wide and are assumed to cost $16 per metre to construct.

The cost of stormwater pipes will vary as a function of depth and pipe diameter however it is assumed that pipes are laid at minimum depth. An example calculation of the costs to place a 375-mm diameter reinforced concrete pipe is shown in equation 3.1.

$$\text{Cost} = O*(A + B + C + D) = \$168.11/\text{m} \qquad (3.1)$$

Where A = cost of pipe = $83.60/m

B = excavation costs = $40/m^3 = $30.75/m

C = sand bed costs = $16/ m^3 = $8.48/m

D = backfilling and trench restoration costs = $40/ m^3 = $30/m

O = oncost factor = 1.1

The cost to place sag pits, kerb inlet pits and extended kerb inlet pits is $1040, $1200 and $1400 respectively. Gross Pollutant Traps are designed as shown in Figure 5. Traditional costs are summarised in Table 3.

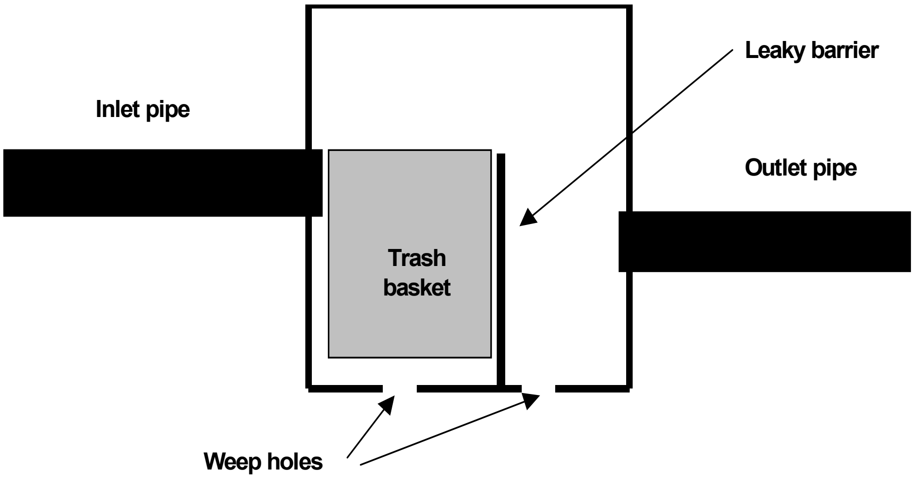

Figure 5: Gross pollutant trap

Table 3: Traditional drainage costs

Item	Unit rate	Cost
Road excavation	$30/m3	$238,275
200 mm thick gravel base	$12/m2	$201,600
AC residential mix 15 mm	$4/m2	$58,800
Kerb and gutter	$47/m	$98,700
Kerb	$26/m	$52,500
Pipe costs		$888,778
Table drains	$16/m	$7,890
Drainage pits		$82,370
Detention basins and GPTs		$181,939
Total		**$1,810,852**

4.0 Water Sensitive Urban Design catchment

The water-sensitive approach was developed in accordance with the requirements of Australian Rainfall and Runoff, Institution of Engineers (1987), the requirements listed above and the following requirements:

- Impervious areas (paths, roofs and road pavements) are not directly connected to the road and pipe systems.
- All stormwater runoff from roofs is directed to a rainwater tank. The tank will have a volume of 10,000 litres, a depth of 2 metres and overflow to a contour bank via a diffuser (see Figure 6). The tank will supply water for irrigation, toilet flushing and hot water use in house with 4 people. Statistical analysis has shown that the tank should be modelled as 49% full at the beginning of the design storm. Cost = $1500 per house (pump, tank, water pipe, down-pipes and overflow system).
- Contour banks and vegetated strips used to reduce stormwater velocities and potential for erosion intercept overland stormwater flow (see Figure 7). The combination of

contour bank and vegetated strip are used on all allotments upslope from road reserves and to intercept overflow from all rainwater tanks. The contour bank will consist of two layers: a sand-gravel base (hydraulic conductivity = 5 x 10^{-4} m/s) to drain the retained water after the storm has passed; and a 0.3 m layer of existing sandy loam with good vegetative cover to protect against overtopping. The contour bank will be planted with native shrubs and grasses. Contour banks are 0.4 m high by 1 m wide and cost $30 per metre.

- All roads are 5 metres wide and have a one-way crossfall (3%) to a grassed swale on the low side of the road (see Figure 7).
- Grassed swales are paired with infiltration trenches to minimise nuisance effects of minor storms. The swale has a maximum grade of 5% and a maximum batter slope of 30% (see Figure 8). The swale and trench system will cascade over concrete driveways. Depth of flow in the swale is less than 0.4 metres. A pit located just upstream of each driveway is used to boost flow into the trench (see Figure 9).
- The infiltration trench is placed under a 0.2 m layer of topsoil (hydraulic capacity = 5 x 10^{-4} m/s) and be filled with 30 mm nominal diameter aggregate (porosity = 0.35) surrounded by geotextile fabric. The geotextile fabric on the bottom and sides of the trench will inhibit infiltration. Cost = $40 per metre of trench.
- Stormwater pipes are used to convey stormwater under roads and perforated pipes are used to increase discharge to gravel trenches.

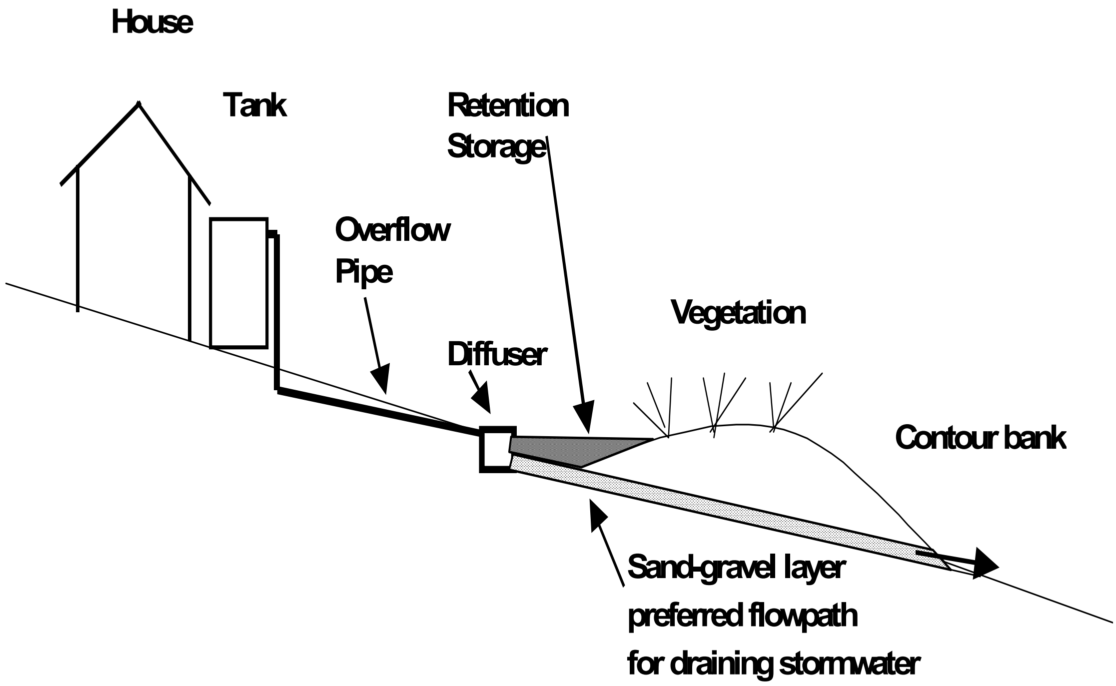

Figure 6: Rainwater tank and contour bank detail

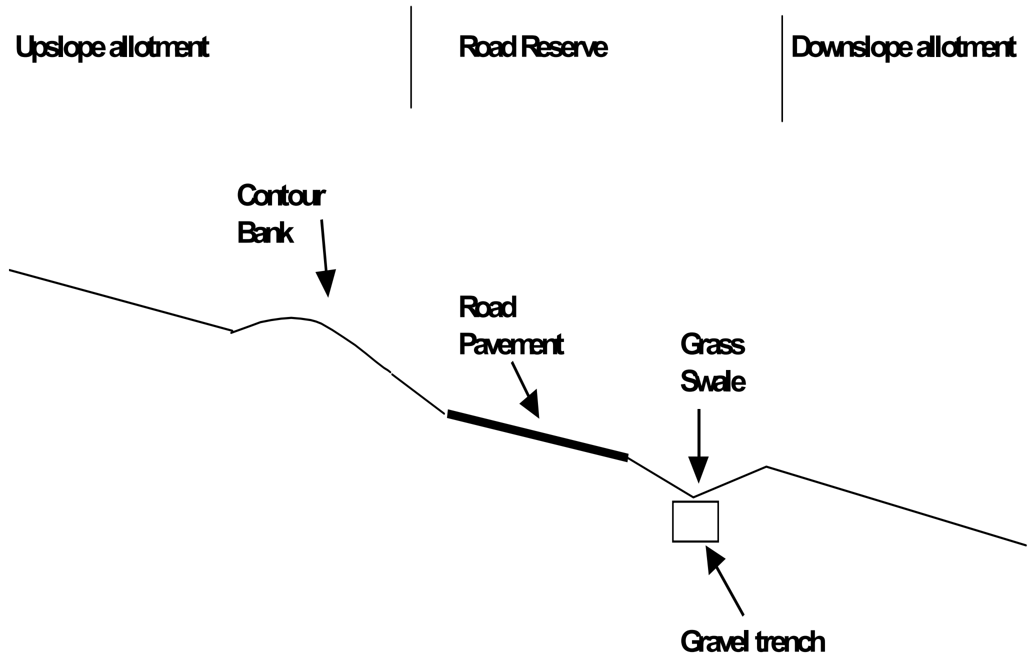

Figure 7: Road cross section detail

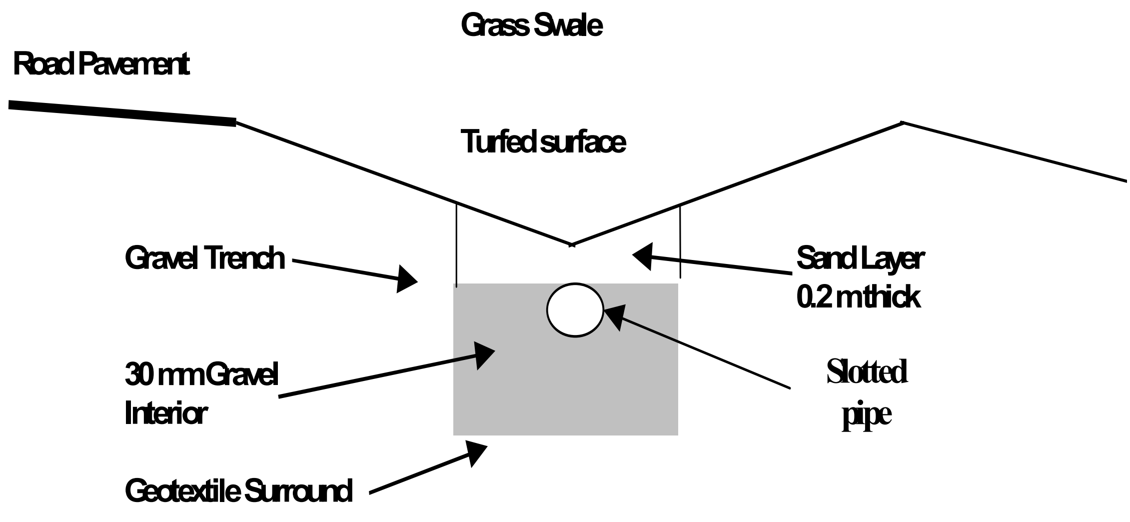

Figure 8: Grassed swale and gravel trench detail

The WSUD solution involves the use of a pollution control pit (Figure 9) which includes a litter trap, a grate and a cascading gravel trench arrangement. The pits are expected to cost $1040 each and are modeled using a 50% blockage factor.

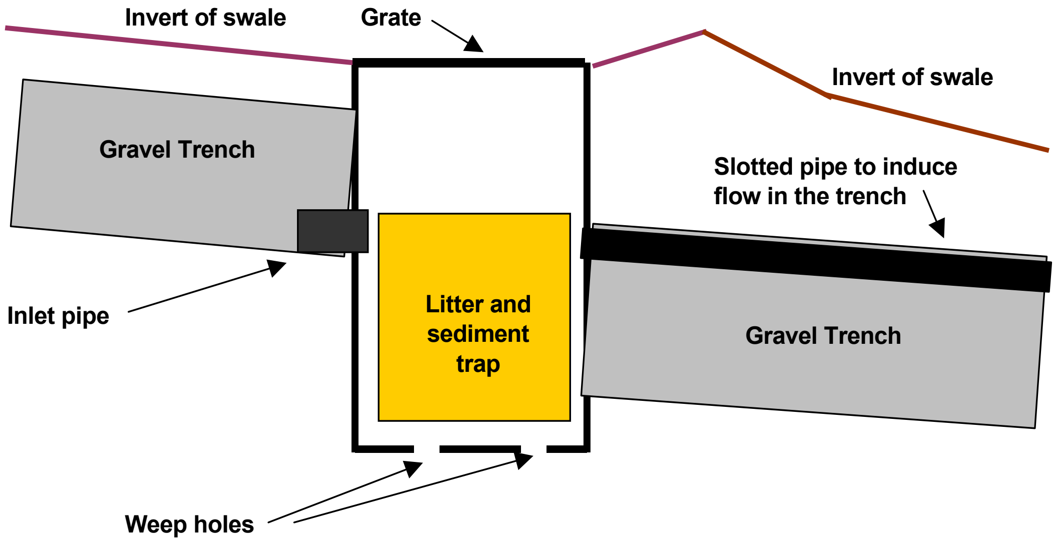

Figure 9: Pollution control pit and swale/trench cascade detail

The WSUD concept used for the subdivision (Figure 10) includes storage of rainwater collected from roofs in tanks for irrigation, hot water and toilet use. Overflow from the tanks, stormwater runoff from paths and allotments is directed to vegetated contour banks.

The contour banks provide retention storage for the stormwater. Overflow and seepage from the contour banks discharges to grassed swales and pollution control pits. Stormwater from the swales and pits is directed via infiltration and slotted pipes into lined gravel trenches. Stormwater discharges along a cascading series of swales and trenches to a settlement basin at each outlet. Stormwater pipes are used to convey stormwater under roads.

The drainage model used in WUFS is shown in Figure 11. The nodes denoted by the symbol S refers to the pollution control pits. The peak stormwater discharges for various ARI storm events is shown in Table 4. Peak discharges are significantly reduced by the WSUD measures that also act as an efficient stormwater quality treatment chain.

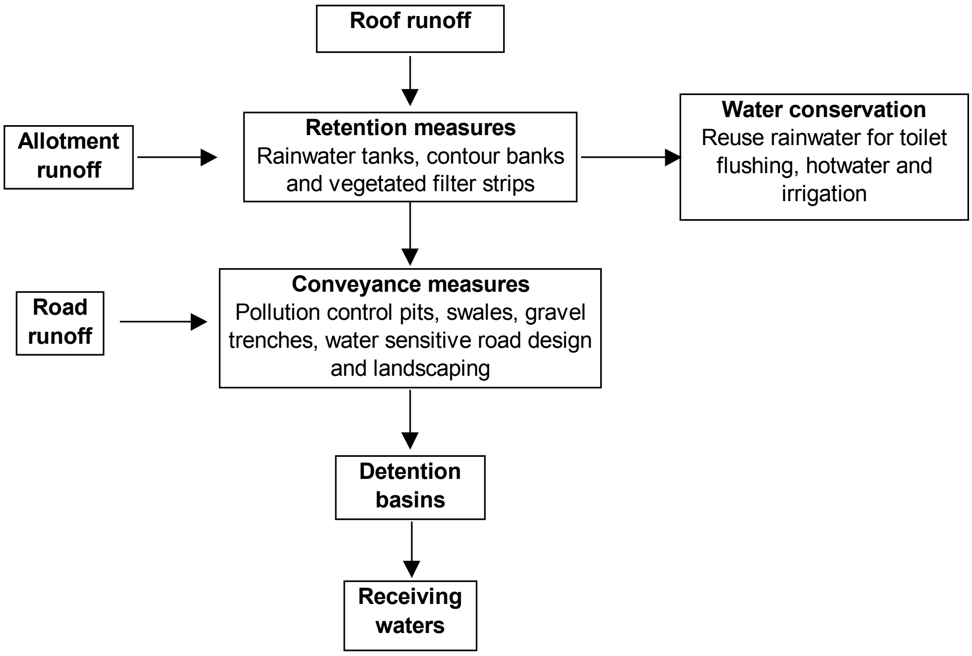

Figure 10: The WSUD concept

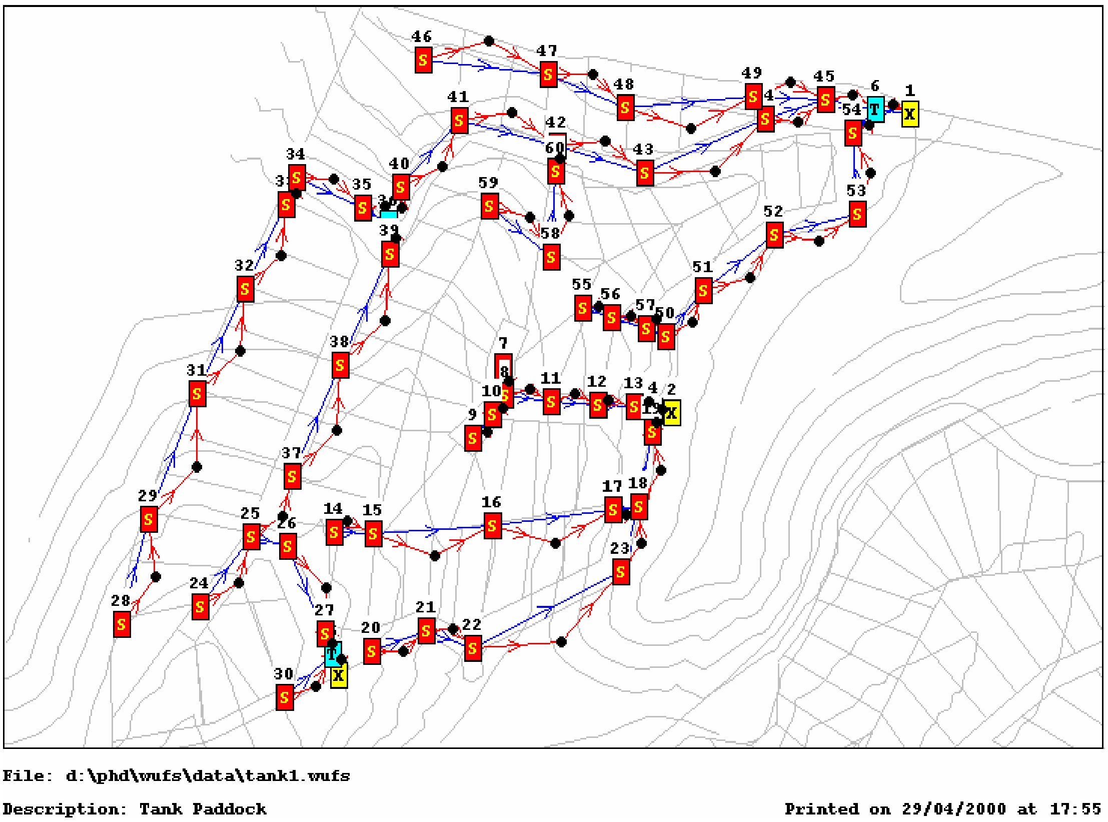

Figure 11: WSUD drainage model

Table 4: WSUD catchment peak discharges

ARI (years)	Q (m3/s)
2	0.064
5	0.131
10	0.171
20	0.348
50	0.606
100	0.827

The road cross-sections (Figure 12) has been designed to contain a major storm event (100 year ARI event) and bulk earthworks are assumed to cost $30 per cubic metre.

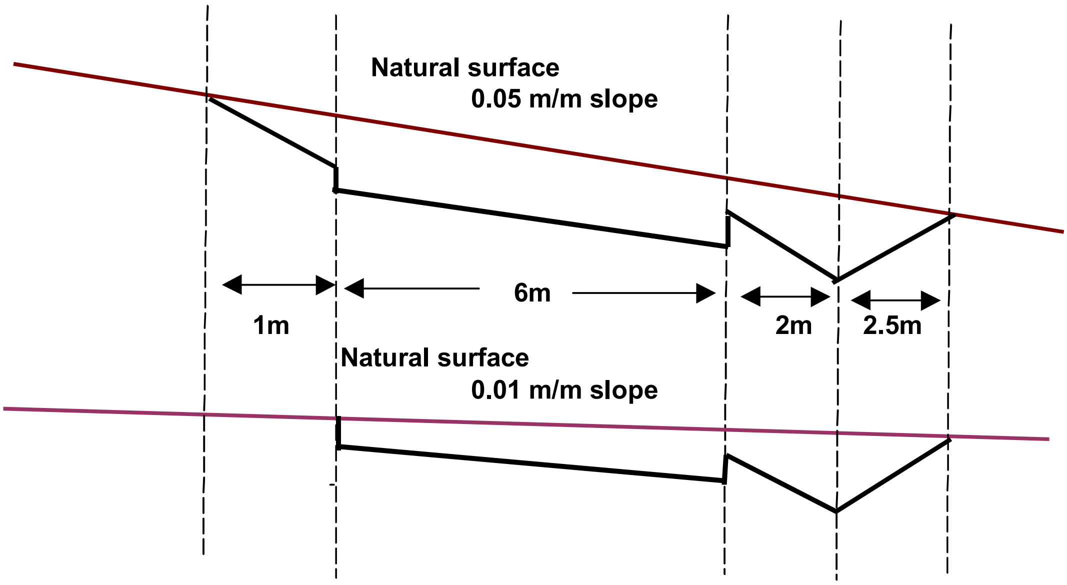

Figure 12: Road cross-sections used for bulk earthworks calculations

The road bulk earthworks calculations were divided into two typical cross-sections (Figure 12) in order to estimate varying site conditions. One thousand metres of road cross-section is assumed to have a natural surface cross fall of 0.01 m/m and the remaining 1100 m of road cross-section is assumed to have a natural surface cross fall of 0.05 m/m.

The road is constructed using a 200-mm thick gravel base, a 15-mm thick AC wearing course, rollover kerb on the high side and gravel shoulder on the low side.

The gravel trenches are 0.5m deep and 0.5m wide. An example calculation of the costs to place a gravel trench is shown in equation 4.1.

Cost = O*(A+B+C+D+E+F+G) (4.1)
Where A = excavation cost = $14/m
B = gravel = $4/m
C = sandy-clay trench/swale interface = $1.6/m

D = geotextile fabric = $2/m
E = slotted pipe = $2/m
F = copus log barrier to keep cars off swale = 4.40/m
G = surface treatment for swale = $8/m
O = oncost factor = 1.1

Note: The majority of swales are formed during bulk earthworks

All other costs are detailed in section 3 and a summary of the WSUD drainage costs is shown in Table 5.

Table 5: WSUD drainage costs

Item	Unit rate	Cost
Road excavation		$176,460
200 mm thick gravel base	$12/m2	$151,200
AC residential mix 15 mm	$4/m2	$42,000
Kerb	$26/m	$52,500
Pipe costs		$55,386
Swales and trenches	$40/m	$133,000
Contour banks	$30/m	$41,500
Rainwater tank systems	$1500 each	$108,000
Drainage pits	$1040 each	$55,140
Detention basins	$30/m3	$30,000
Total		**$845,186**

The relative construction cost for the WSUD approach is $845,186.

5.0 Discussion

The relative construction costs of the traditional and WSUD approaches for the Tank Paddock have been calculated. The costs are $1,810,852 and $845,186 for the traditional and WSUD approaches respectively.

The WSUD approach results in a cost saving of $965,666. That is a 53% cost saving when compared to the traditional approach. The cost savings have resulted from a reduction in the use of stormwater pipes, reduced bulk earthworks and reduced detention basin sizes.

The WSUD treatment chain of retention storages (rainwater tank, contour bank and gravel trench) create reduction of peak stormwater discharges that bring about the reduced requirement for infrastructure.

The use of rainwater stored in rainwater tanks for irrigation, in hot water systems and for toilet flushing is expected to result in a 42% reduction in mains water use. The reduced cost of water supply infrastructure resulting from decreased mains water demand has not been calculated in this study.

Similarly, the WSUD treatment chain is expected to produce improved stormwater quality when compared to the traditional approaches however this study has not evaluated stormwater quality.

The traditional stormwater design generated considerable stormwater peak discharges and volumes. Although large detention basins were able to limit these discharges to acceptable levels high runoff velocities will be experienced in overland flowpaths. This will increase the potential for erosion within and downstream of the subdivision.

6.0 Conclusion

A study has been undertaken to compare the performance of traditional and WSUD developments for the Tank Paddock site. Construction costs and performance of the different stormwater management approaches has been evaluated.

The WSUD scenario revealed significantly reduced stormwater peak and volumetric discharges. A direct benefit of this result is considerable reduction in construction costs (53%). Indirect benefits of this result include reduced potential for erosion damage, safer roads during large storm events and reduced contaminant transport to Hexham swamp.