DESIGNING STORMWATER SYSTEMS FOR CONSTRUCTION AND WHOLE OF LIFE CONSIDERATIONS

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ABSTRACT (200 WORDS MAXIMUM)

Detailed stormwater design can often overlook important construction considerations including include safety of construction, other services, and integration with other design elements. Whole of life asset management and maintenance requirements (including safety) should also be considered in the design process.

If construction and whole of life requirements are not considered during the design process it can lead to either construction difficulties or long-term asset management issues. The risks are additional construction costs, redesigning under pressure situations, under performance of the asset due to unfulfilled maintenance, unexpected asset upgrades within the expected design life and safety issues during construction and operations.

This paper firstly presents a number of issues and approaches to design that should be considered when undertaking detailed stormwater design. Secondly, the paper presents a number of examples of construction difficulties and their solutions. The paper is based on information obtained both through research and the experience of the authors.

KEYWORDS

Stormwater, safety, maintenance, constructability, whole of life

PRESENTER PROFILE

Stefan Whiting is a senior stormwater engineer with 12 years' experience, predominately in stormwater design and construction in New Zealand and Ireland. He has extensive experience in the design of stormwater networks and hydraulic structures for roading projects, rail networks, infrastructure upgrades, retail developments and landfills in both green field and brownfield retrofit situations.

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1 INTRODUCTION

Detailed stormwater design can often overlook the necessary construction, operation and maintenance considerations. This may be more so with increasingly complex projects, shorter project timeframe and budget constraints. Recognising, considering and incorporating fundamental construction and operational issues into the design process is paramount to reduce errors, delays and cost overruns. This will reduce risks to designers and clients, and increase the likelihood that a quality end product is delivered.

Construction considerations include safety of construction, constructability, other services, and integration with other design disciplines. Whole of life asset management and maintenance requirements (including safety) should also be considered in the design process.

This paper aims to present a number of issues and approaches to design that should be considered when undertaking detailed stormwater design. The paper also presents examples of design and construction difficulties encountered and their solutions.

The purpose of the paper is to evoke thought and discussion within the stormwater industry. The paper should not be taken as a definitive guide to these matters. Reference should be made directly to legislation, standards and guidelines on these matters.

In this paper the term "stormwater system" refers to any stormwater network, device or structure.

2 ISSUES

2.1 GENERAL

The design of a stormwater system is not as simple as a drawing with a catchpit, manhole, some level information, and maybe a long-section, for a contractor to build. There are a number of fundamental issues, no matter the size of the project that should be considered during the design process:

- Safety during construction, maintenance and operation
- Integration with other design elements
- Integration with and around other services
- Constructability
- Maintenance requirements
- Whole of life considerations.

The issues are fairly self-explanatory and in some cases simple to include in the design. However, they can be easily overlooked, especially with time pressures to complete a design. Each issue is discussed in more detail, with a focus on stormwater, in the sections below.

Due consideration of the issues allows obstacles to be identified, and ideally resolved, before a project is actually built to reduce or prevent:

- Errors – redesign, troubleshooting during construction and reconstruction
- Delays – due to errors
- Cost overruns – due to delays and errors
- Disputes and claims, in worst case scenarios
- Underperformance of the asset – unfulfilled maintenance or unexpected asset upgrades
- Unsafe stormwater systems for construction, maintenance and operation.

2.2 SAFETY IN DESIGN

Is the design safe?

There is increasing emphasis on designers to consider and incorporate safety into their designs, including stormwater systems. A survey carried out on this topic by Site Safe indicated that while 80% of engineers believed they kept safety in mind during design, only 30% of constructors believed that they did (IPENZ, 2004).

Health and Safety in Employment Act (1992, 2003) is the key legislation in New Zealand. The Act establishes liabilities of engineers in their various roles as employees and employers, and as designers and consultants. The whole Act is predicated on the identification and management of hazards. By careful analysis, the designer, in partnership with the client and the construction team, can have a significant impact on the hazard level in construction. This is particularly true in the area of elimination of potential hazards by seeking alternative solutions and appropriate materials and by actively considering high-risk tasks such as work at height, trenching, etc (IPENZ, 2004).

Safety in design (SiD) is about eliminating or controlling risks to health and safety as early as possible in the planning and design of items that comprise a workplace, or are used or encountered at work or by the public. The earlier in the design process you intervene the easier it is to make changes that benefit everyone downstream. Most site level action is aimed at isolating or minimising the hazard, but the opportunity to eliminate a hazard at the drawing board through good design is one that should be seized with both hands (Construction Industry Council, 2006).

SiD can be defined as "the integration of hazard identification and risk assessment methods early in the design process to eliminate or minimise the risks of injury throughout the life of the product being designed…" (Australian Safety and Compensation Council, 2006).

When considering SiD regard needs to be given to:

1. Safety of construction – can the stormwater system be constructed safely?
2. Safety during operational – will the stormwater system be safe during operation to both the public and the maintenance staff?

It is the designer's responsibility to incorporate (and in most cases demonstrate) that the SiD issues have been designed into the stormwater system as far as practical. One SiD methodology uses a risk register to identify risks and mitigation actions.

It may not always be possible to design out all safety issues through the design process. Some risks will be carried through to construction, and/or operation and maintenance. These risks can be mitigated via operation and maintenance plans that identify the hazards and minimise the risk through procedures.

2.2.1 SAFETY OF CONSTRUCTION

Can the design be safely built?

The first and principle objective of any small or large construction project is the safety of the construction staff and public.

On large design and build projects there is usually the opportunity to interface with the contractor (and other design disciplines) to contribute to the SiD risk register outlined above. On smaller projects it is not always possible to obtain contractor feedback during the design process. In this instance the designer should take the time (even on projects with tight budgets) to understand the site and identify the potential risks. Such risks with respect to stormwater include:

- Working at heights/depths – ground conditions and trench stability
- Installation of new works within roads, rail corridors, airports – traffic hazard working in live environments, constrained working spaces and hours
- Working in or around water
- Presence of existing services – which is discussed in more detail in Section 2.4
- Hazardous materials – existing materials/services, contaminated ground or groundwater

The designers "must take all practical steps to ensure the safety of the end users…" (IPENZ, PN07, 2006). Where risks are not able to be designed out, a methodology to minimise the safety risk during construction should be considered. During construction it is also the responsibility of the constructor to "take all practical steps to the safety of all workers…and others who may be affected by the works" (IPENZ, PN07, 2006).

Environmental safety during construction is also an important issue to consider in the design process to minimise the impacts on the environment it is being constructed in. This is particularly important to stormwater, which often involves works in or near streams and coastal environments. Consent conditions usually outline the minimum environmental requirements to be met on a project. However, they may not outline how the conditions are to be achieved.

2.2.2 OPERATIONAL SAFETY

Can the stormwater system be safely operated and maintained?

With increasing safety awareness, greater emphasis is being given to operational safety (OS) in the design process. OS is both the safety of operation/maintenance staff and that of the public. OS is a significant whole of life consideration in stormwater systems. Stormwater system elements which can present safety issues include:

- Road catchpit grates – they could cause cyclists' wheels to jam in the grates (if the grate elements are parallel with the road) or cause slippage
- Manhole lids – lifting ("popping") of lids during stormwater surcharging could cause accidents to pedestrians (including falling into manholes) as well as accidents to vehicles. Dislodged lids may also "invite" unauthorised entry (refer to "stormwater outfalls below"
- Manhole entry – safety issues relate to manhole air quality and problems climbing into and out of manholes negotiating limited size manhole openings, maybe long access throats, hard to reach access rungs, or uncertain ladder fixings. For deep manholes where intermediate landings may be a benefit, the landings themselves may create operational safety risk by complicating the extrication of any maintenance personnel in difficulty below a landing. There is also the added safety risk of entry into manholes located within road carriageways

- Stormwater channels – falls from unfenced, vertically sided channels. Building requirements normally require fencing for heights greater than 1.0 m. Clearly, falls from heights less than this still pose risk of injury

- Deep and fast flowing water – in drainage channels, natural streams and overland flow paths create drowning hazards

- Stormwater outfalls – outfalls larger than about 450 mm diameter and with no grille can result in unauthorised entry into the outfall pipe (often by curious children).

The safety issues may not be resolved easily. This is because safer catchpit grates may be less hydraulically efficient, preventing lids lifting may overpressurise a pipe system or cause property flooding via backup along stormwater connections, manhole entry on road carriageways may be unavoidable, fencing stormwater channels could lead to floatable debris buildup on the fencing with resultant water level rise, and grilled outfalls run the risk of blockage from the inside from debris conveyed down the outfall pipe.

With regard to manhole entry, some jurisdictions (e.g. South Australian Water Corporation) prohibit the installation of access rungs or ladders in manholes to deter entry except by authorised personnel with specialist equipment or to protect against safety issues arising from rusting fixtures. The risk of accidentally falling into manholes with "popped" lids could be avoided by installing fall-arrest safety grilles beneath the lids.

It is apparent that operational safety aspects should be considered during the design of stormwater systems and that appropriate consultations with stakeholders should take place to agree on the level of safety built into the design.

2.3 INTEGRATION WITH OTHER DESIGN DISCIPLINES

How does a stormwater system integrate with other design elements?

The concept and process of integration with other design disciplines is self-explanatory, although not always undertaken. It is not uncommon for a particular design discipline (not just confined to stormwater) to design an element of a project in silo, without understanding it in a wider project context or considering how it integrates with other design disciplines.

Identification, ongoing discussion and coordination with other design disciplines should be undertaken when designing a stormwater system. For example, design of a stormwater system for a new road requires coordination between:

- Geotechnical – retaining walls, footings, tie-backs, geogrid layers, embankment slopes, settlement, subsoil drain locations
- Structural – building offsets, bridge columns and abutment locations
- Other utilities – location of other services to avoid clashes or properly connect to these (discussed in more detail in Section 2.4),
- Pavement designs – geometric layout, pavement design (thickness), kerb and barrier locations
- Construction – sequencing, constructability (refer to Section 2.5), construction loading on pipes.

There are also other constraints and requirements that need to be incorporated into the design, such as:

- Design standards – national and local authority
- Consent conditions
- Environmental issues.

2.4 OTHER SERVICES

The presence of other services along the alignment of new stormwater services is one of the most critical aspects of designing to avoid "surprises" during construction. Every effort needs to be taken to accurately locate services to prevent compromise of the stormwater design or the services. Issues are:

- Abundance of services – water, wastewater, overhead and underground power, gas, telecommunication including fibre optic, street lighting, and other services abound and proliferate as communities develop. The relatively large size of stormwater services and the lack of flexibility of depth for gravity drainage systems creates a high risk of a clash with these services. There have been instances when unexpected services have been discovered during construction, which have led to the aborting of works installed because of an irreconcilable clash.

- Criticality of services – severance of services can have serious implications such as loss of water and power supply and loss of telecommunication. The services can also be very expensive to repair.

- Hazard – severance of a service during construction can create serious safety risk as in the case of puncturing a gas main or the shorting of a power cable. (It is clearly important to avert danger at the design stage by accurately locating services before site penetration investigations are undertaken).

- Locating services – the accurate location of services may not be straightforward and may require several approaches for success. Receipt of available drawings (starting with the online service "beforeUdig") is a must. It is strongly advised that the service locations are confirmed on site by test holing to expose the services. Water jetting and vacuum excavation can be used for this purpose which significantly reduces the risk of damaging the services during the exploration. Surface locators deploying radio frequency (RF) and radar technology can be effective in identifying the approximate location ("designation") of services. RF locators are used to detect metallic services, while radar based locators can detect non-metallic services including plastic pipes and fibre optic cables.

  Other means of services location include the use of CCTV inspection to confirm the position of services passing through existing drainage pipes, together with local knowledge.

- Trenchless installations – accurate location of existing services may be particularly important in the case of trenchless installation of stormwater pipes, not only to avoid physically clashing with the services but also to prevent ground heave during the installation process affecting the services. Minimum clearances are often required between installed pipe and existing services.

The ideal solution is to have a thorough understanding of the existence and location of other services to enable risk-free design and construction to take place. This allows the arranging, if necessary, of the diversion of services or redesign of the stormwater system to avoid clashes. When choices are made to defer investigation to the construction phase, such as test holing to physically locate services, the designers, constructors and clients should understand the high risk from doing this, and have appropriate contingencies in place.

The accurate location of services is coming more to the fore through the implementation of subsurface utility engineering (SUE) practice (ASCE, 2002). The discipline utilises all the above means to accurately locate services and to record their location using global positioning system (GPS) devices and equipment. 3-dimensional design software also makes resolution of clashes simpler once all the services are properly located.

Where a clash is unavoidable, it is usually not acceptable for a stormwater pipe to "duck" under the service with the use of a U bend. This encourages the deposition of sediment in the bend during low runoff periods which can result in reduced pipe capacity and ability of the pipe to convey higher runoff. Services other than gravity drainage services can usually be diverted below or over the stormwater pipe.

Solutions where gravity drainage services clash with, say, a stormwater pipe include:

- Allowing the service to pass, with protection, through the stormwater pipe
- Constructing a stormwater manhole at the crossing of the service to create additional flow area around the service
- If the gravity service is a sewer pipe with sufficient base flow and peak flow, it may be possible to create an inverted siphon running below the stormwater pipe such that the siphon remains free from blockage.

2.5 CONSTRUCTABILITY

Can a stormwater design be constructed practically and cost effectively?

Generally the easier a stormwater system is to construct the more economical it is. Therefore, "constructability" of the stormwater system is another key element to consider in the design process.

The term "constructability" is referred to in IPENZ Practice Note 13 – Constructability, 2008, as:

- "The extent to which the design of the building facilitates ease of construction, subject to the overall requirements for the completed building
- A system for achieving optimum integration of construction knowledge and experience in planning, engineering, procurement and field operations in the building process, and balancing the various project and environmental constraints to achieve overall objectives
- A system for achieving optimum integration of construction knowledge in the building process and balancing the various project and environmental constraints to maximise achievement of project goals and building performance."

A simple example is sizing a stormwater manhole with multiple inlet and outlet pipes at various levels and angles. A manhole size may be chosen from a guidance table or chart, but in reality the manhole may be too small to physically fit the multiple pipes. The result is:

- Time delays to remove the existing manhole, size and procure a bigger manhole

- Increased project costs to redesign, procure and construct a new manhole.

A simple solution is to draw (in plan and too scale) the pipes and angles, and overlay manhole sizes to determine the most suitable size, considering suitable offsets and clearances between pipes.

As with safety of construction (Section 2.2.1) working with contractors is considered beneficial to understand constructability issues, with resolution through improved design or specific construction methodologies to ensure a constructible design is achieved.

2.6 WHOLE OF LIFE CONSIDERATIONS

The design stage offers the greatest opportunity to incorporate whole of life considerations. Whole of life considerations that should be taken into account (based on observation and experience and supported by published literature (e.g. PSU, 2004) as part of the stormwater design process should include the following:

- Design appropriateness – a main objective of a stormwater system is to satisfactorily convey stormwater runoff to protect residential and other development from flooding. The design and technology adopted for the stormwater system needs to be appropriate for the entire expected lifetime of the system, and it needs to fulfil its design objective throughout the life of the system.

  The design should be able to accommodate future predictable changes in parameters including population, land use and runoff flow rates.

- Expected life – unless a deliberately limited lifespan is required from a new stormwater system, the system should be designed for a minimum period of 50 years and preferably longer, say, 100 years.

- Whole of life cost – consideration should be given for the operation and maintenance costs over the life of the project in conjunction with the initial capital cost to determine the most cost effective design solution over the expected life of the asset. It is increasingly desirable that designed systems require low maintenance costs over their lifetime.

- Functional reliability – a key element in the acceptability of a system is its ability to operate successfully with little downtime and disruption. Stormwater systems should therefore be physically robust and durable.

  Stormwater systems can be exposed to significant stress from large, sudden flow rates, passage of large objects through them, and damage potential during cleaning operations. Material selection and system design should take these into account.

- Aesthetics – the value of a stormwater system is enhanced when aesthetics as well as function is taken into account. The visual attractiveness of an installation often has a significant bearing on the acceptance of the installation by the community.

  Stormwater examples of a blending of the two facets are the construction of artificial rock over beach pipe outfalls to conceal them, and the replacement of concrete stormwater channels with landscaped natural channels.

- Environmental effects – clearly, the effect that an installation has on the environment is an important whole of life consideration. Beneficial effects should be maximised and adverse effects minimised.

  Beneficial environmental effects of a stormwater system could include the sustenance of life along a watercourse and the maintenance of a healthy marine area by the continuing supply of fresh water. To realise these benefits and not create adverse environmental effects, stormwater quality and the method and location of discharge have to be satisfactory

- Operational safety – increasing attention is being given in design to the whole of life operational safety of installed works. Stormwater systems can present particular safety risks. This aspect is discussed further in Section 2.7.

- Sustainability – is covered by many of the other items, but it also includes the a consideration of the environmental effects of the materials and construction techniques used

- Recycle – a "cradle-to-cradle" approach to the "recycling" of a project at the end of its service life is an important whole of life consideration and can contribute significantly to the overall sustainability of a project

  Once the service life has been exhausted (after extending it as far as possible), physical components of the installation should either be able to be used for other purposes, safely left in the ground or recycled

Some of these whole of life considerations are bound in broad definitions of "value for money". NZTA (2009) cite HM Treasury with the definition of value for money, being "the optimum combination of whole-of-life costs and quality (or fitness for purpose) of the good or service to meet the user's requirement".

2.7 MAINTENANCE REQUIREMENTS

No installation can operate maintenance-free during its service life. Good design is characterised by the amount of thought that has been given to facilitating the maintenance required for the successful operation of a stormwater installation. For stormwater systems, maintenance requirements generally involve the inspection, cleaning, and occasional repair of catchpits, and pollutant capture devices such as gross pollutant traps, filtration devices, sedimentation and detention ponds, inlet structures in watercourses, pipe outlet structures, and low impact design (LID) devices such as rain gardens and swales.

Maintenance of pipes and manholes is also required. Pipe joint failures resulting in ingress or egress of water or resulting in root intrusion are common problems. Inadequate sealing of manholes often results in undue entry of groundwater and surface water into the manholes.

Key maintenance considerations include:

- Access –a fundamental consideration for effective maintenance is effective access to and into a structure. Vehicular access is essential, and thought should be given to the type of maintenance vehicle required. For example, a utility vehicle may be sufficient for accessing an inlet grille for inspection/cleaning, whereas a truck access may be required for emptying a gross pollutant trap.

Access into structures such as manholes and other underground chambers should take into account ease of access with respect to road traffic, the type and size of entry lid, and the method and means (rungs, ladder, winch) of descending into the structure). Some manholes have an excessively long throat between the lid and the main chamber which makes entry difficult.

- Ultimate disposal of pollutants – maintenance activities do not end when, for instance, a treatment device or pond is cleaned. Equally important is the transportation and ultimate disposal point of waste materials.

- Cost –maintenance costs can be considerable over the service life of a project and they should be taken into account at the project design stage. Prudent selection is required between solution options involving capital intensive/low maintenance cost and lower capital/high maintenance cost.

- Safety – during maintenance is part of operational safety and whole of life operational safety, which are discussed further in Section 2.2.1.

3 EXAMPLES

3.1 BOWDEN ROAD LITTER TRAP

The litter trap installation at Bowden Road, Mt Wellington, Auckland, is presented as an example of a successful installation providing for ease of maintenance and operational safety.

The litter trap, together with a settling basin, constitutes a stormwater treatment facility at the discharge end of a 290 ha catchment area comprising 50% residential and 50% commercial/industrial land use. The 12.3 m wide concrete rectangular discharge channel can handle a 1 in 100 year design flow of 72 m^3/s. The settling basin extends across the full width of the channel and is 17 m long. The litter trap is installed on the water surface of the settling basin.

Initial thinking on the installation of the litter trap followed conventional "symmetrical" lines. Namely, installing the trap in the middle of the basin and, on occasions, pulling it over to the side with cables to access it for cleaning. The pulling over would have required loosening it from two of its four moorings and then re-mooring it in the middle of the basin after cleaning.

The finalised "asymmetrical" design (see Photograph 1) avoids the need for any pulling operations and provides a permanent mooring next to an access platform which itself is easily accessible via a ladder from the access road above. Litter scooped from the trap is placed in bag nets which can be lifted up to the disposal truck by a hoist on the truck.

Photograph 1: Bowden Road litter trap

The litter trap needs to be cleaned very regularly (monthly or more frequently). The installation makes for an easy and safe maintenance process.

3.2 SERVICES CLASH AND RESOLUTION

In a recent project a stormwater design crossed very close to a number of existing services including water and wastewater. CCTV investigation using ultrasound detection was used to locate the existing wastewater services. The CCTV method had an accuracy of +/-200 mm. The CCTV method was selected over an alternative option for test holing for cost reasons.

The design necessitated a cross-over of proposed stormwater and existing wastewater pipes with minimal separation. The minimal separation meant that there was a potential construction risk due to the inaccuracy associated with the level of the wastewater pipe. Unfortunately this risk was realised when during construction the wastewater pipe was discovered to be was almost 200 mm higher that that determined by the CCTV investigation. By this stage of the construction it was too late to redesign the stormwater invert levels. Due to the proximity of other existing services, rerouting the stormwater line was also not possible. The remedial solutions were extremely limited.

Therefore, after discussions with the local authority, the contractor, and other senior engineers the most practical design solution was to run the wastewater pipe directly through the stormwater pipe, as shown in Photograph 2. The section of wastewater pipe through the stormwater pipe was replaced with a new PVC pipe with flexible gibault connections either side of the stormwater line.

Photograph 2: Wastewater pipe through stormwater pipe

It is appreciated that this is not the most ideal solution given the invert level of the wastewater pipe in relation to the stormwater pipe. However, given the site constraints it was considered the most practical solution. The capacity of the stormwater pipe was also checked to ensure it could pass the design flow given the reduced cross-sectional area available.

Although the redesign, approvals and notice to contractor were completed within two days, the implications to the project were:

- Additional design
- Additional local authority assessment and approval
- Construction delays while the design and approvals were
- Additional design, compliance and construction cost
- Non-standard outcome.

This example outlines:

- The importance to obtain as accurate services information as possible. There may be additional cost involved in undertaking a more detailed survey of the existing services, but ultimately it may prove to be a most cost effective solution.
- A workable design solution that, although not ideal, did not significantly compromise the stormwater design.

3.3 NORTHERN GATEWAY TOLL ROAD STORMWATER DESIGN

The Northern Gateway Toll Road (ALPURT B2 project) provides a number of examples where various construction, maintenance and safety issues were considered and incorporated into the stormwater design. Three specific examples include:

- Catchpit manhole design – constructability and safety in operation
- Treatment device selection – whole of life considerations
- Culvert fish passage and habitat – constructability and environmental considerations.

The three specific design examples are discussed in more detail below.

3.3.1 PROJECT OVERVIEW

The Northern Gateway Toll Road project is a 7.5 km extension of SH1 from Orewa to Puhoi. The route was constructed through a diverse landscape containing steep topography, large tracts of native bush, regionally significant streams and estuaries and areas of pastoral farmland.

The stormwater design objectives were to meet:

- Road safety criteria
- Conditions of resource consents
- Project objectives for environmental excellence.

A key philosophy of the overall design was to minimise the motorway footprint. The geometric design uses as narrow a formation width as possible to minimise the motorway footprint in order to reduce environmental impacts and stormwater volumes.

3.3.2 CATCHPIT MANHOLE DESIGN

The narrow footprint reduces the roadside berm width to a minimum allowable width of 1.1m. This limited the possible use of roadside swales and also created a challenge in locating constructible stormwater collection catchpits and lead connections to conveyance manholes and pipelines within the roadside berm.

The narrow berm width necessitated the innovation of an important element in the pavement network drainage design – a "flow through" system whereby stormwater inlets were incorporated into the manhole design to create "catchpit manholes", as shown in Figure 1. There are no sumps in the catchpit manholes.

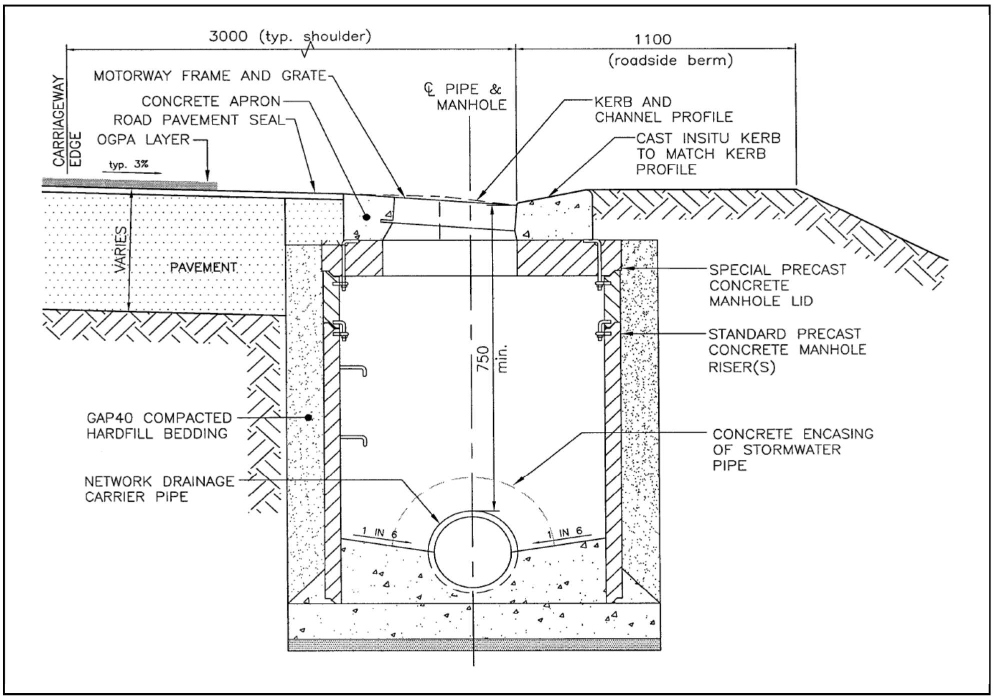

Figure 1: Typical detail for "flow through" catchpit manhole

The other consideration driving the decision to eliminate catchpit sumps was maintenance. Catchpit sumps are difficult to maintain in an operating motorway environment due to high hazard from traffic when working on the motorway. Traffic control measures to isolate the work activity from traffic hazard such as lane closures are very expensive. The "flow through" system reduces the maintenance requirements of the catchpits.

With the "flow through" system the sediment normally captured in the catchpit sumps is collected at the forebay of the wetland that services that stormwater network. Removal of sediment from the forebay of the wetland is more cost effective as there is just one cleanout location per network compared to multiple catchpits. It also requires less frequent cleanout due to the greater storage volume (forebays where oversized).

3.3.3 SELECTION OF TREATMENT DEVICES

Wetlands were considered to be the optimal solution for stormwater treatment due to their relatively low cost. The whole of life costing for wetlands for this project were more than for wet ponds but less than for tanks or filters. The sustainability of the wetlands was scored the highest (see Figure 2) because of the low material usage and benefits from ecological and landscape enhancement of the environment.

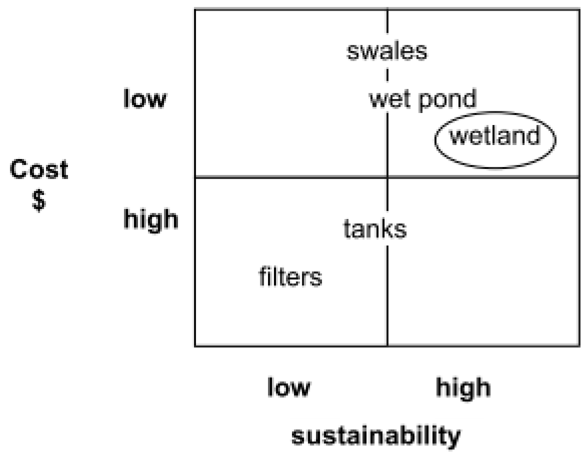

Figure 2: Whole of life and sustainability assessment of stormwater treatment options

3.3.4 CULVERT FISH PASSAGE AND HABITAT

Northern Gateway Toll Road includes 6 major culverts that convey existing watercourses under the motorway. The culvert design criteria included:

- Minimum culvert diameter for maintenance – 1.6 m diameter
- Fish passage and habitat requirements for some of the culverts.

An innovative approach was taken to design constructible in-culvert habitats and fish passage, as shown in Photograph 3(a) to (c). This was done by designing and building a series of artificial riffles within the culverts. Initial concept designs were for rock and/or concrete blocks to be fitted into the culverts after the pipes were laid. However, there were health and safety concerns for construction staff who would need to carry these heavy objects into the culverts (180m long).

The SiD solution was to construct the riffles from light weight, pre-moulded plastic sheets (upside-down, oversized ice trays) 2.4 m long at set distances within the culvert. The plastic sheets were light, could more readily be carried and were easily bolted to the base of the culvert pipe. A matrix of smaller rocks and sand was then embedded around the plastic sheets.

Photograph 3: Artificial riffles: a) plastic sheets as manufactured; b) placed in culverts and c) installed in culvert as riffles with matrix of natural materials.

4 CONCLUSIONS

Detailed stormwater design can often overlook the necessary construction, operation and maintenance considerations. This may be more so with increasingly complex projects, shorter project timeframe and budget constraints. Therefore, recognising, considering and incorporating fundamental construction and operational issues into the design process is paramount. The issues that should be considered, no matter the size of a stormwater project, include:

- Safety issues in design, construction and operation
- Integration with other design elements
- Integration with and around other services
- Constructability
- Maintenance requirements
- Whole of life considerations.

Recognising, considering and incorporating the issues into the design process is paramount to reduce or prevent:

- Errors – redesign, troubleshooting during construction, reconstruction
- Delays – due to errors
- Cost overruns – due to delays and errors
- Disputes and claims, in worst case scenarios
- Under performance of the asset.

Due consideration of the issues early in the design process is also likely to increase the likelihood that a quality end product is delivered.

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