Evolution of Raingarden Design at the City of Sydney

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Abstract

The City of Sydney has developed a Decentralised Water Master Plan which has ambitious water quality improvement objectives. Raingardens have been identified as an effective way to achieve the water quality targets.

Since 2008 the City of Sydney has been working on the evolution of the design, construction and maintenance of streetscape raingardens. This process has led to the development of raingarden standards and designs that have now been recognised as best practice and are being implemented in other council areas.

It has been demonstrated over this period that the key features to successful streetscape raingardens is to maximise ponding depth, install entry pit systems and implement clever planting. Ongoing observations, auditing and water quality testing have supported the successful design progression that has occurred over the last seven years.

Collaboration between design, construction and maintenance staff has been vital to identify and resolve issues.

The City of Sydney reaps additional benefits of this work as the new standards are being applied to the major urban renewal areas. This has the greatest potential to improve the quality of the water draining to Sydney Harbour and Botany Bay.

The City of Sydney is continually re-evaluating and aiming to maximise the raingarden performance, minimise the maintenance requirements and improve visual amenity.

1. INTRODUCTION

The City of Sydney (the City) is committed to meeting the challenges of reducing stormwater pollution. The community consultation in 2007 and 2008 for the Sustainable Sydney 2030 identified a desire to reduce stormwater pollution. This was included in the 2030 Vision and this has been supported with various policies, strategies, and actions to achieve the goal.

The City has developed a Decentralised Water Master Plan (DWMP) which has ambitious water quality improvement objectives. This plan includes actions and strategy's to reduce sediments and suspended solids by 50 % and nutrients by 15 % from reaching Sydney Harbour and Botany Bay.

Raingardens have been identified as an effective way to achieve the water quality targets. Since 2008 the City has been actively including the raingardens in their capital works infrastructure upgrades. The City has installed over 140 raingardens during this time. These range from small streetscape systems to large systems for catchment based stormwater harvesting schemes.

This paper focuses on the streetscape raingardens and will explain the challenges that have been faced during implementation of this infrastructure in a highly urbanised environment. Along with detail of how the systems evolved to minimise maintenance, improve performance and increase their visual amenity.

This paper describes the evolution in the design, construction and maintenance of the systems. Many features developed are now recognised as best practice and are being implemented in other council areas.

The paper will also explain the collaborative journey the organisation has taken to achieve the results. The findings from trials, observations, testing and system auditing will be discussed. Their effect on the design progression will be explained.

The benefit of these improvements is amplified when the new standards are adopted in the design of the City's major urban renewal areas. Here they can have the greatest potential to improve the quality of the stormwater discharging into our waterways.

1.1. Why Build the Raingardens?

The City of Sydney Local Government Area (LGA) covers 2,699 Hectares of highly urbanised catchment. It was modeled that over 3800 tonnes of stormwater pollutants are generated by the catchment every year. These pollutants are:

- Suspended Solids: 3192 tonnes
- Gross Pollutants: 575 tonnes
- Nitrogen: 56 tonnes
- Phosphorus: 7 tonnes (Source: Decentalised Water Master Plan 2013)

Residents' concerns about stormwater pollution in the Sustainable Sydney 2030 community consultation resulted in the 2030 Vision including the target to reduce stormwater pollutants by 50 %. Sustainable Sydney 2030 was adopted in 2008 with the City's commitment to make Sydney a Green, Global, Connected City.

The vision included a number of objectives to reduce stormwater pollutant loads under the, *A Leading Environmental Performer*, direction.

The vision proposed to achieve this by renewing stormwater infrastructure by installing water sensitive urban design (WSUD) in the catchment. WSUD was to be included as part of the City's works. Raingardens were included opportunistically in capital works since 2008 in accordance with the directive.

The directive was further backed in 2011 by the City's Raingarden Policy that sought to 'achieve the opportunistic integration of raingardens into streetscape and public domains, until the completion of the DWMP'.

The DWMP was developed in 2011 & 2012 and was endorsed in 2013. This plan includes actions and strategy's to reduce sediments and suspended solids by 50 % and nutrients by 15 % from reaching our waterways. The DWMP outlined the water targets to be achieved by four key activities, namely:

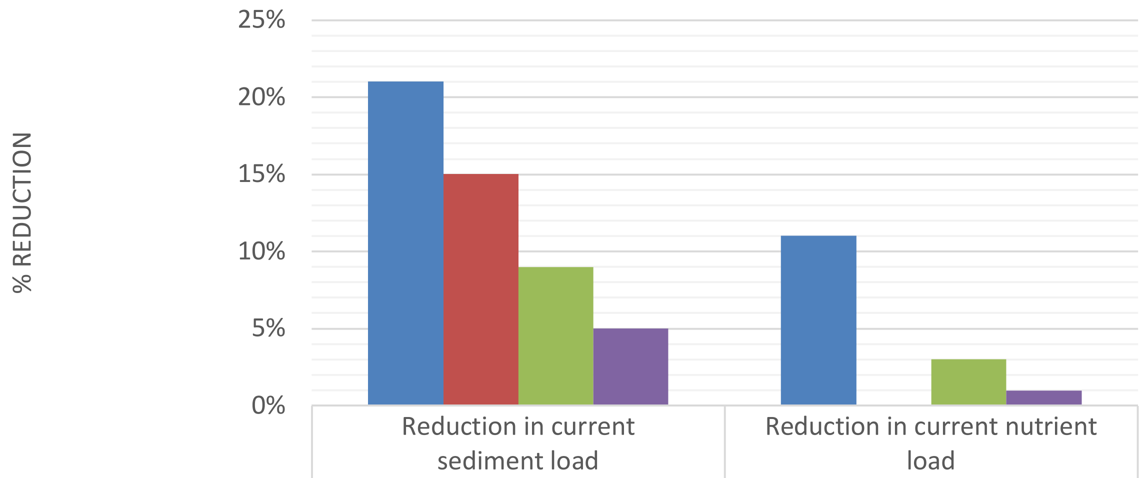
1. WSUD in new development,

2. Retrofitting of the drainage network with gross pollutant traps,

3. Retrofitting of public open space with a combination of raingardens, swales and wetlands in at least 10 per cent of the opportunities,

4. Incorporating WSUD during at least 10 per cent of opportunities presented by renewal of road and other streetscape projects.

The extent to which each of these activity areas meets the pollution reduction targets is shown in Figure 1. New development in the City is responsible for the greatest proportion of the pollution reduction including the reduction of suspended solids by 21 % and nutrients by 11 %, or 42 % and 44 % of the totals respectively.



	Reduction in current sediment load	Reduction in current nutrient load
New Developments	21%	11%
GPTs	15%	0%
Public Open Space	9%	3%
Road and streetscapes	5%	1%

Figure 1: Pollution reduction targets identified in the DWMP for each of the key activity areas.

1.2. Where are they installed?

There are limited locations to install new raingardens in the City's highly urbansied catchment. Finding the space to install a suitable raingarden can be challenging.

The City has an extensive pedestrian safety, traffic calming and cycleway capital works program across the whole LGA. These projects have provided the opportunity to include raingardens in the upgraded urban landscape. Since 2008 the City has installed over 140 raingardens. These range from small streetscape systems to large systems for catchment based stormwater harvesting schemes.

To date the City has installed nearly 3000 m^2 of streetscape raingardens with a further 5000 m^2 installed as part of the Sydney Park Stormwater Harvesting Scheme.

In a significant number of streetscape works the no stopping areas at intersections were built out with kerb extensions. These kerb extensions were to be landscaped were possible. These landscaped areas were the opportunity to install raingardens.

Integrating raingardens into the programmed capital works reduced the unit cost of the raingarden installation. This was due to a significant amount of the base infrastructure costs, such as road and kerb works, were required for the traffic safety improvement works. The landscaping works were substituted with the raingarden works.

The high density population of the City means on street parking is highly valued by the residents. Removal of parking spaces is difficult and hard to justify for water quality improvement reasons. The inclusion of the raingardens in the kerb extensions allowed their installation will minimal parking loss.

Where practical, the raingardens where extended in to the footway to increase the available treatment area.

As outlined in the DWMP, the inclusion of WSUD in new developments was the City's largest opportunity to reduce stromwater pollution. There are many major urban renewal areas including the Green Square Town Centre and the surrounding precincts, Barangaroo, Harold Park, Everleigh and Ashmore Estate.

A major benefit to the City by the work that has been developed by the streetscape raingardens is the transfer of information into the designs of the major urban renewal and redevelopment works. This is an essential transference of information since the City is to take ownership of many of the development assets and their maintenance. The City needs to minimise the maintenance costs of the assets while meeting the water quality performance targets.

1.3. Initial designs and constraints

For the streetscape projects, the available space had a significant effect on the size of the raingarden. The kerb build out of the no stopping areas at intersections was generally the area where the raingardens could be installed.

Once the initial available area was established then an assessment of the site is prepared to determine whether a raingarden is suitable. This included but limited to a catchment assessment, an assessment of the surrounding infrastructure such buildings, trees and utility services, an assessment of the subgrade material and the maintenance requirements.

Once the available raingarden area was determined the initial designs in 2009 were guided by the available Facility for Advancing Water Biofiltration (FAWB) Specifications at the time and examples of systems that had been previously installed.

The erosion at the entrance was a major concern in the initial designs. Controlling the rate and speed of water entering a raingarden is vitally important to controlling erosion in the raingarden. This was controlled by only installing the raingardens with a street longitudinal grade of less than 5% and the installation of a rock energy dissipation pad at the entrance.

The design of depth of the ponding was generally 50 – 150 mm. The limitation to this depth was reducing the water ponding depth to below the invert of the gutter at the entrance to stop water from backing up in to the street. The other major limitation was the perceived safe height for the step in level between the road and footpath adjacent to the raingarden.

The type of system used was a major consideration in the design of the initial raingardens. Unlined systems were the preferred type since they infiltrate water and recharge the ground water. These were predominately installed in the southern part of LGA where there are sandy soils and houses are offset from the boundary. In the north and west, the soils are less suitable for infiltration and buildings are built on or close to the boundary. In these areas lined systems were more commonly used.

A submerged zone system was installed on a streetscape project which had favorable site constraints. Generally they were not practical to install due to the increased depth required and the construction complications due to existing utilities.

All the systems were lined for the full depth along the road edge to minimise the potential for water to enter the road pavement. To date there has not been a road pavement failure next a raingarden due to water ingress in to the pavement.

1.4. Construction of the early systems

In 2009 and 2010 the City's contractors and staff had limited experience with the construction of raingardens. A major issue that emerged with the construction of the early projects was the importance of the attention to detail when constructing the layers of a raingarden. During the early projects contractors and council staff tended to fill in the ponding area since they were not used to working with depressed garden beds. This resulted in a number of garden beds that had to be excavated back to the required levels.

The gardens were further filled when the area was planted since the excavated soil for the plants was spread over the ponding area. This became more of an issue when large plants were used in the initial planting. A level allowance for this was applied to the finishing levels before planting.

Educating staff and contractors about the finished product was crucial to achieving the tight level tolerance required in raingardens.

On a number of occasions the City used experienced consultants to manage the layering stage. This has been effective in both producing a better product and building up the skills of contractors and staff.

The initial designs specified a 0.5 mm unreinforced polypropylene (PP) liner. The PP liner was problematic to install for the small raingardens with complicated shapes and services to work around. In these situations is it is difficult to cut and weld a PP liner. A shotcrete lining system was devised with one of the contractors. This was found to be effective and practical. The City's contractors have been using a 50 mm thick layer of Shotcrete as the lining since 2010.

Over pouring of concrete has been an issue around pits and kerbs. This prevents planting to the edges, reducing the area of treatment and effecting the visual aesthetics of the systems. This is a quality control issue that has needed constant attention.

1.5. Observations of the early systems

Once a number of the systems had been installed their performance was observed from 2010 to 2012 and a number of features were determined that were leading to poor outcomes.

Ponding Depth

When the raingarden was designed and constructed too shallow, then they are more prone to blocking with debris and silt at the entrance. The reduced volume caused the systems to by-pass quickly into the overflow pits and reducing the volume of water treated through the filter media. The tight construction tolerance made it difficult to construct to the correct levels with it usually resulting in the ponding depth being less than what was designed.

It was deduced from the observations that the ideal water ponding depth should be 200 mm with a minimum of 150 mm and a maximum of 300 mm. At this depth there is some freeboard for construction tolerances and the system can still function with some buildup of silt and debris.

Small and Narrow Systems

Small and narrow were prone to problems. They were less effective and need regular maintenance to function. They had limited pond water storage and were prone to overtopping quickly into the overflow pit reducing the volume of water passing through the filter media. Visually they had poor outcomes with the plants struggling to survive due to being smothered by silt and debris and the inlet pit dominated the space.

To reduce the negative impacts, the minimum raingarden size adopted was 6 m^2, excluding the area of the grate. The preferred minimum width to be used in future designs was 1.5 m.

Entry Point

A common problem that was found in our raingardens is the entry section was prone to filling up with debris and silt. This became unsightly and caused plants to die off in the affected area. In a number of locations with flat road grades and shallow raingardens there was substantial volumes of silt deposited upstream of the raingarden. This required regular street cleansing operations to remove the silt.

The erosion at the entry of the raingardens was another issue that was observed. This was anticipated and a number of rock amour/dissipation arrangements were constructed as part of the early projects to varying degrees of success.

Maintenance

The raingardens were effective in filtering the silt and debris. However, like all filters required maintenance to maintain both the visual amenity and water treatment functionality. Careful and time consuming cleaning in and around the planting was required to remove the debris. Particular care was taken to be sure plants were not damaged. Picking debris by hand had Work Health Safety issues such as risks due to needle stick injury. On average it took two staff about thirty minutes to clear the debris from an average size 20 m^2 raingarden.

The Impacts of Existing Trees

The surrounding trees had varying effects on the function of the raingardens. At a number of locations the shading caused by a large nearby tree did have an impact on the survival of the raingarden vegetation. Locations where there were many street trees upstream tended to cause a lot of leaf litter to end up in the raingardens requiring more maintenance.

1.6. Internal Stakeholder consultation

Ongoing consultation between internal stakeholders was very important in the success of these projects. Group meetings were held with the internal stakeholders from design, construction and maintenance to discuss issues and solutions.

Ongoing informal meetings and discussions throughout the whole period between design, construction and maintenance staff and contractors was an effective way to identify issues and devise solutions. The consultation process was important to get internal support required for the success of the projects.

1.7. Revised designs 2011 -2015

The raingarden designs were reviewed following the observations and feedback on the systems that had been installed up to 2012.

Increased Ponding depth

Increasing the ponding depth was seen as a way to improve the functionality of the systems. The deeper ponding area then created its own issues. How to create a system that worked but was still compliant with design standards and requirements. A number of design details were then created to overcome these issues. One of these was using step down edges. This reduced the garden edge level to being 150 – 200 mm lower than the surrounding kerb and footpath levels. This way the batter slope width could be reduced and provide the maximum flat ponding treatment area possible for the raingarden.

Maximising the ponding depth was a driver in the designs with many complicated site constraints being resolved with terracing, step down structures and clever planting.

The increased depth allowed the raingarden to still function even if it started to accumulate silt and debris. This allowed the maintenance to be less frequent while still having a functional system. The reduced maintenance is not ideal but practical since there are limited resources to maintain the systems.

The increased depth had multiple benefits such increasing the ponded water volume without water backing up in to the street or overtopping the overflow system. Therefore, maximising the amount of water passing through the filter media. The increased depth allowed some freeboard for construction tolerances.

Water Entry Points

The increased depth had further complicated the issue of how to control erosion at the entrance. A number of rock in a concrete pad arrangements had been designed and constructed with varying degrees of success. The most successful being a system where the water would drop 150 mm from the gutter invert to a dissipation system at the base of the raingarden. The idea was to take as much energy out of the entering water as possible. The system reduced the silt to build up in to the road withless potential for stormwater to back up in the street.

The issue with all the dissipation systems was they still allowed all the silt and debris to collect in the vegetation. They also had limited capacity to slow the entering water effectively.

Debris and silt smothering plants and its removal was still a maintenance problem. The poor visual appearance that this produced was not ideal. This can lead to further damage since people are more likely to throw more rubbish in the gardens and walk through them if they are in a poor state. This is a problem for garden beds and raingardens in the City.

Water Entry Pits

From the observations the key to reducing the maintenance demands was to collect the silt and debris before it entered the raingarden. This led to the next design progression which was the design of the entry pits in 2012.

The entry pit is a modified road gully pit at the entrance of the raingarden. The pit has a baffle wall to separate the two sides of the pit. One side is in the road and the other in the raingarden. The water enters the pit by a standard grate and lintel arrangement, then passes under the baffle and exits via a sloped hinge grate in to the raingarden. The debris is trapped in the pit while the water is allowed to pass through. The silt is removed by sedimentation caused by the drop in water velocity passing through the pit. The sloped grate is located on the raingarden floor so the height difference in the gutter to the raingarden pushes the water through the pit.

Photo 1: The raingarden at Telopea Street with an entry pit.

The primary treated water drains in to the raingarden ponded water area at a reduced velocity significantly reducing the erosion potential at the entry. This allowed raingardens to be installed on roads with longitudinal grades steeper than 5 %. This substantially increased the potential locations where they could be installed.

The system also had the design feature where the gutter overflow water is directed on to the exit grate to reduce the potential for erosion from larger flows entering the raingarden.

The two grate system provided two cleaning access points which allowed the cleaning of the pit even if a car is parked over the main grate.

The pit has multiple weep holes to reduce the potential for water to pond in the pits. This keeps the caught material as dry as practical. This reduces the potential for caught organic material to breakdown in anoxic conditions and be a source of dissolved pollutants.

The dimensions of the pit were guided by using existing drainage infrastructure components and the hydraulic flow through the system. The initial pit design had a storage capacity over 1 m^3. It was anticipated the pit would require cleaning every 3 months to maintain its cleaning efficiency.

1.8. Planting

The planting of the raingardens has developed during this time. Generally the City has used the standard plants that are specified in the guidelines suitable for raingardens.

How the species were planted and arranged changed and this had a big impact on improving their visual appearance, gaining community support, minimising maintenance and improving performance.

The raingardens are highly visible since they are on busy urban streets. Initially the raingardens were planted with tube stock in an unstructured arrangement. This created relatively bare gardens in the urban landscape for months until the plants established. This contrast was further exacerbated when they are located next to formally planted garden beds which are densely planted with 200mm pot sized plants. At times the contrast was a source of negative feedback from the community.

The first major change was to increase the size of the plants initially installed in the raingardens to 200 mm pot sizes. This created an instant green impact at a comparatively small increase in project cost.

The next change was in response to the deeper gardens that were being installed. Plants such as the *Westringia Fruticosa*, which could be groomed in to a dense hedge, were installed around the outer edge of the raingarden. This had multiple benefits since it filled the step down area around the edge, it formed a barrier around the garden that discouraged people and animals from walking through them and it created a visual border to the raingarden.

The next progression was to plant the raingardens with structured arrangements. The range of plants used was increased to improve their visual appearance. The water treatment plants were strategically located to maintain the water treatment functionally. Many of the later projects had gardens beds and raingardens similarly planted to minimise the contrast. The visual improvements have been very important in gaining community support for the systems.

1.9. Observations on the Revised Designs

In 2012 the new entry pit system was trialed next to the latest rock dissipation system. In the inner city suburb of Paddington, the new entry pits were trialed on two gardens in Walter Street. Another two raingardens in a parallel street, Alexander Street, had the latest rock dissipation system. Both streets had similar catchment characteristics including size, percentage of impervious area and number of street trees. The entry pits proved effective in stopping the majority of the debris from entering the raingardens in Walter Street. The corresponding raingardens in Alexander Street had significant volumes of debris strewn throughout the vegetation.

The new entry pits were effective at reducing the erosion at the entrances to the raingardens at Walter Street. The road grades were over 7 % which would have made the installation of a raingarden unsuitable with a standard rock dissipation system.

Photo 2: An example of a raingarden with a dense hedge border.

Each pit takes about ten minutes to clean with the City's vacuum truck. The entry pits were deepened on the second trial site following discussions with the maintenance team. The increased storage volume will increase the return time required to clean the pits and further reduce maintenance demands.

The entry pit was then installed on two unlined raingarden systems in Telopea Street Redfern. The system entry pit storage was increased to nearly 2 m^3. The installation of the entry pits at the new location had similar positive results.

The rate at which the pits required cleaning varied significantly. The catchments of the two systems in Redfern were similar in size and numbers of trees. The pit on the southern system would fill three to four times faster than the pit on the northern system. This observation has occurred with subsequent installations.

The entry pits can reduce the overall maintenance time by up to two thirds. The pits are capable of holding a volume of silt and debris equal to a 100 mm layer covering an average sized raingarden in a way that is contained and easily cleaned. A significant portion of maintenance work that has been previously done by the landscape staff has been transferred to the drainage maintenance staff with the installation of the new entry pit system. The landscape staff have been active at monitoring and informing the drainage maintenance staff to clean the pits so their workload is reduced.

1.10. Independent Testing

In 2012 and 2013 the City worked with the University of Western Sydney (UWS) to conduct independent testing on the function of some of the City's raingardens.

Derry *et* al (2013) stated in the *A Performance Monitoring Framework for Raingardens as Decentralised Stormwater Treatment Systems in the City of Sydney* report that the 'lined raingarden complied with the percentage removal targets of the DWMP with regard to all parameters'.

Furthermore it was also stated that, 'heavy metals were very effectively removed during pilot testing by all raingardens' and also the raingardens had a 'substantial removal of faecal indicator bacteria occurred, with up to a 2 log or 99% removal being noted for enterococci'.

Over the two year period there was numerous tests performed and these were limited to a small sample size of raingardens. It is planned to conduct additional testing using a larger sample size of raingardens.

1.11. Audit Results

All the streetscape raingardens in the LGA were audited in February and March 2015. 141 gardens were visually inspected, assessed against a set of 16 criteria and a series of photos were taken for each site.

The criteria and the overall rating bands used in the audit were developed between stakeholders within the City. The overall rating system was set to a high standard. To achieve a satisfactory overall rating the systems needed to be functioning well with 50 % - 80 % of plants in good health, a minimum ponding depth of between 30 - 80 mm and only a small amount of silt and debris in the system.

Of the 141 systems, 60 % achieved an excellent to satisfactory rating, a further 25% where still functioning but generally unsatisfactory and a further 15% were in a poor condition.

The five characteristics of raingardens performing from excellent to satisfactory where:

- More than 50 % having an entry pit. The higher performing systems had a higher % of entry pits.
- They had a detention depth of more than 100mm.
- They had healthy dense vegetation.
- There was minimal silt, litter and debris throughout the raingarden.
- They had a good cover of gravel mulch.

The characteristics of the good performing systems are features of the current standard designs.

The audit results showed that the direction that the raingarden designs have been progressing towards was producing tangible results which has led to improved performance, increased visual amenity and minimised the maintenance.

1.12. Future Actions

The largest potential to reduce stormwater pollution is in the redevelopment of the urban renewal areas. The biggest benefit for the City with the development of the design standards is their incorporation in the design of these urban renewal areas. This will allow the City to guide the design and installation of future assets that have an improved performance while minimising the maintenance requirements.

The audit has highlighted some poorly functioning systems and these systems have been identified to be upgraded to the new standard.

The City will continue to review and look at ways to improve the performance of raingardens.

1.13. Conclusions

The City has been and remains committed to reducing stormwater pollution reaching Sydney Harbour and Botany Bay. This was documented in the Sustainable Sydney 2030. This has been supported with various policies, strategies, and actions to achieve the goal. Namely, the DWMP which includes actions and strategy's to reduce sediments and suspended solids by 50 % and nutrients by 15 % reaching our waterways.

Raingardens are an essential part of the City's plan to meet its water quality targets.

Since 2008 the City has been actively including raingardens in its capital works projects. Over this period more than 140 streetscape raingardens have been installed.

During this time the design, construction and maintenance of these systems has evolved to improve their performance and visual amenity while minimising their maintenance requirements.

The major improvements have been made by increasing the depth of detention; intercepting and trapping silt and debris before it enters the raingarden and improving the planting arrangements. To make these improvements possible a range of design standards have been developed by the City including the entry pit system. Many of the standards have been recognised as best practice and have been used by a number of councils.

The collaborative approach between design, construction and maintenance staff has been essential to achieving the progressions.

The progressions have been validated by the results of a 2015 audit of the systems across the LGA. The results showing that the new design features strongly correlate to improved asset condition.

The UWS testing has shown that installed systems are meeting water quality improvement targets.

The benefits of these improvements are multiplied since the new standards are being adopted in the design of the City's major urban renewal areas. Here they can have the greatest improvement in the quality of the stormwater discharging in to Sydney Harbour and Botany Bay.

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