Coastal Stormwater-Challenges and Opportunities

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Introduction

In the natural environment rainfall runoff directly enters the ocean via rivers, creeks, lakes and lagoons that can be intermittently open or closed. It can also indirectly find its way to the ocean as a dispersed groundwater flow through beaches and dunes. When development takes place these natural systems tend to be disrupted. Roads, buildings, lawns, gardens, and driveways, to name but a few, cut through natural drainage paths and collect, concentrate and re-direct rainfall runoff into what is conventionally referred to as storm water. Further, rainfall that would have previously found its way into the groundwater system by infiltration is intercepted by non-porous hard surfaces and re-directed to stormwater systems thereby increasing the volume of water taking direct routes to the ocean and reducing the time it takes for that water to reach the ocean.

Stormwater systems can take many forms; some piped, some open drains and others simply exploiting natural features such as depressions and natural watercourses. The increase in hard surfaces combined with the more rapid delivery of water through more hydraulically "efficient" stormwater systems creates greater flow concentrations in far shorter time spans thereby tending to convert an often rather leisurely natural process into a more instantaneous and frantic event.

Attempts have been made in recent years to mimic the original timing of flow arrival at the coast, and its water quality, by the introduction into developments of detention tanks and artificial wetlands utilizing the principles of Water Sensitive Urban Design (WSUD, Argue, 2008). While these interventions do provide some relief to the timeframe and quality, their effectiveness is often compromised by the way in which simple formulae are applied throughout catchments rather than actually attempting to reproduce the previous natural system and the limited replication of the groundwater re-charge process. That is, the approaches being adopted are often well intentioned and to varying degrees effective, however the outcome they produce is generally compromised by the generalized simplicity of the application to individual catchments and in particular to the failure to take into account groundwater flow through various soil types.

A detailed examination of overall storm water management is however beyond the scope of this paper. The paper focuses on the management of stormwater as it reaches the coast.

Stormwater outfalls

There are a number of different routes by which stormwater from developed areas can reach the coast. Each has its own characteristics and management issues.

- Rivers and lakes

- Creeks, lagoons and intermittent water courses
- Constructed stormwater drainage systems

Rivers and lakes

Generally, because of the relatively large scale of their natural catchments, the additional volume of storm water created by developments makes up only a small percentage of outflows from rivers and the larger lake systems. Further, the size of these water bodies tends to dissipate the impact of the additional discharge and in particular its arrival time at the coast This means that their coastal discharge points usually do not suffer additional physical impacts as a result of the stormwater loads generated by developments in their catchments.

The major potential issue for the coast, associated with stormwater discharge into these water bodies, is from pollution generated by developed areas, particularly from road runoff, sewage overflows, pesticides, nutrients, industrial waste, urban detritus such as plastic and paper products, sewerage system overflows and the flushing of overcharged groundwater in un-sewered areas.

Rivers and lakes can act as receiving bodies for stormwater from developed areas. However potential pollution issues should be addressed prior to the stormwater leaving its own system and entering the receiving body. This requires particular attention to the construction and maintenance of pollution interception and nutrient stripping devices/systems. It should however be recognized that while such devices/systems can be designed to operate effectively at low to medium flows, they often prove ineffective during high flow events and, if flushed out in high flows, may even discharge pollutants that had been previously trapped. Therefore regular cleaning/maintenance is essential. Sensitivity analysis of potential pollution outcomes resulting from severe events is important. Fortunately at such times the natural flows in the receiving water body are often sufficiently high to dilute and diffuse stormwater input.

Creeks, lagoons and intermittent watercourses

Depending on their size in relation to that of the developed areas, creeks, lagoons and intermittent watercourses can experience anything from minor to major impacts from the flow regime changes brought on by stormwater discharge from the developments. Apart from the pollution issues raised above, a significant increase in flows can radically alter the impacts of stormwater conveyance systems on their exit points at beaches. Usually these smaller water systems are more vulnerable to pollution and also they more rapidly transport pollutants to the coast. In addition, whereas the larger rivers and lakes usually jet any pollutants well offshore and, because of their discharge velocity, produce greater mixing and diffusion, the smaller creeks, lagoons and watercourses tend to deliver pollutants directly to the beach or near shore zone with far less potential for initial dilution or diffusion.

With development in their catchments, creeks that once only occasionally broke out across a beach may experience more frequent breakouts. Further, the scale of these breakouts may be greater. The increase in frequency and magnitude of breakouts can mean that the beaches are more regularly eroded at, and adjacent to, the discharge point thereby lowering the average height of the beach berm, hence making the adjacent shoreline more vulnerable to wave induced erosion events. The increase in the magnitude of the discharge can also result in sand being transported further offshore than previously, thereby causing an associated increase in the frequency and magnitude of the short-term fluctuations of the beach. The increase in scour at the mouths may allow storm waves to penetrate further up the creek as well as opening up a path to enable waves to attack any developments located close by either side of the creek entrance.

As with creeks, the duration and frequency of intermittently open lagoons breaking out across a beach can increase as development takes place in their catchments. This can produce more frequent episodes of beach erosion in the vicinity of the entrance. Often this affects a far greater length of the beach, than with creeks, as sand moves into the lagoon entrance by littoral drift from the adjacent beach in order to restore the lagoon's entrance delta and re-construct the beach berm that had been washed out during the lagoon breakout phase.

More frequent openings of lagoons tend to delay beach berm recovery and hence, make it easier for future breakouts to occur. Further, developments located near the entrance tend to be more vulnerable to wave erosion. The interaction tends to generate a positive feedback system that impacts not only on the regularity of break out but also the potential for shoreline erosion near the entrance.

Lagoons that break out more often due to stormwater ingress also tend to experience greater fluctuations in salinity. As compared with the predominantly brackish regime that previously dominated, a more regular breakout regime, caused by stormwater input, produces increased periods of fresh water during runoff events and more saline conditions when the lagoon is open to the ocean. These greater fluctuations, and the longer time exposure to tidal influences, can have significant, and often profound, implications for the overall ecology of the lagoon. The water cycle of intermittently open and closed lagoons has been described by Gordon (1990).

In their natural state many beaches have intermittent watercourses immediately behind the dunes. In some cases, where there is a back dune swale region and a clogging of the naturally porous sediment due to siltation, an intermittent lagoon may also evolve.

Intermittent watercourses tend to only break out in major rainfall events. The remainder of the time they act as temporary storages for smaller runoff events. The water so captured permeates into the ground water table or is taken up by the surrounding vegetation and/or evaporates. Given the porous nature of dune sand the groundwater re-charge role of intermittent water courses can be vital to the survival of competent dune vegetation and hence dune stability. However the contribution of back-beach intermittent watercourses to assisting in the natural management of dune and beach erosion is often overlooked. Unstable dunes can result in beach erosion due to wind born sand losses.

Development of their catchments often results in the infilling of these intermittent lagoons (for example at both Avalon and Newport on Sydney's northern beaches) thereby reducing or eliminating their buffering effect along with the opportunity to retain small events so that groundwater recharge can occur. Further, the influence of stormwater on these often fragile ecological system is to cause the systems to break out more often, thereby reducing the opportunity for recharge and also often, to significantly modify their surrounding vegetation.

Intermittent back beach watercourses have traditionally been seen as providing a "natural" drainage path for conveying stormwater away from the developed areas. Hence the fate of many of these natural watercourses is all too often to have their "efficiency improved" by being concrete lined or piped.

Stormwater drains at beaches

Where stormwater drainage systems terminate at a beach they typically take one of three forms: a pipe/culvert leading across the beach; a pipe/culvert onto the rock shelf at a headland or; a pipe/culvert which ends at the back of the beach at either a headwall or into a drop structure which discharges at normal berm level or into the substrate of the beach.

Pipe/culvert crossing beach

Where the pipe/culvert crosses the beach it is usually at, or just below, normal berm level and terminates near low water level. Beaches are always in a state of flux and can also experience either long-term accretion or recession. The unstable nature of the location and height of beach berms means that any pipe across a beach tends to be either exposed, thereby creating issues for both safety and beach amenity, or buried and therefore choked and unable to fulfill their function when needed. Further, unless cross-beach stormwater systems have adequate foundations, generally substantial piles, they tend to collapse during storm erosion events and given such events are also often associated with rainfall, the erosion/beach scour problem is compounded.

The outfall at Collaroy Beach, Sydney, is a case in point. It was replaced twice as a cross-beach pipe; the second being constructed with piled supports. Then, following the 1970s storms it was re-built as a substantial culvert, with piled foundations, and now it is again collapsing, for the forth time in 50 years.

A further issue is the repeated water hammer like effect waves can have on the flow in pipes and culverts as the wave impacts on the exposed ocean end. This can lead to joints being blown apart and/or “blow holes” developing at weak points in the pipe/culvert. The water hammer affect can be readily managed by providing purpose fitted pressure relief systems, but if not managed can cause major damage.

In the case of box culverts, beach scour can expose their underside allowing wave action to compress trapped air against headstocks thereby resulting in significant, “instantaneous”, uplift forces. This can produce structural damage to the concrete underside and/or dislocation of the culvert sections from their headstocks.

Where beach berm accretion buries, in whole or part, the outfall end of a cross-beach stormwater pipe/culvert, it will tend to not operate satisfactorily, if at all, when required. In the late 1960s investigations undertaken by UNSW Water Research Laboratory concluded that if “*the pipe is completely blocked for a relatively short distance, then it is most unlikely that storm water will force an exit within the duration time of a storm”* (Hattersley and Stone, 1968). The researchers developed what has been colloquially named the “hammer head” outfall for a proposed outfall at Manly Beach, but this did not proceed so it was first installed on outfalls at Collaroy and Newport beaches.

Cross-beach stormwater drains can act as groins, locally modifying the littoral drift with build up on one side and erosion on the other; depending on the wave energy flux at the time.

Pipe/culvert discharging on rock shelf

For stormwater systems that exit on rock shelves the major issues are visual amenity, safety, structural integrity and adverse impact on the water quality of any adjacent swimming venues such as rock pools. Often it is possible to site pipes in clefts in the rock so they present neither a visual nor a safety issue and the opportunity to adequately anchor the pipe to the rock overcomes foundation challenges hence the water quality impacts tend to become the principal concern. Unfortunately the opportunity to locate stormwater outfalls on rock shelves is often limited by the distance from the area to be drained to the nearest headland and the available drainage slope of the back beach stormwater system.

Discharge structures at the rear of beaches/front of dunes

Where stormwater systems discharge at the back of a beach they not only cause local scour thereby making themselves more vulnerable but also they can promote beach erosion. This may adversely impact on adjacent properties due to direct berm scour and/or wave penetrations up the scour channel.

On a beach subject to long-term erosion and/or significant storm erosion, back beach stormwater systems often fail as the dunes they were constructed in, and which provide their foundation, erode. Following major storms it is not uncommon to see the remains of such systems scattered on a beach with the broken end protruding from the dunes and disgorging stormwater into a developing scour hole at the base of the dune.

There can be an on-going water quality/health issue due to ponding on the berm caused by this type of outfall design. It is therefore generally not good practice to terminate stormwater systems at the back of a beach. However there are some locations where this is unavoidable in which case careful consideration must be given to the coastal processes of the site, any adverse impacts and the structural integrity of the system and in particular the design of its foundations. Alternatively consideration should be given as to whether the entire drainage system could be re-focused to an alternate receiving body such as a river or estuary.

For situations where the potential flow rate, even during severe events, is likely to be modest, there may be the opportunity to construct a drop structure at the back of the beach (front of the dune line) which has a permeable base or infiltration trench so that flows can be dissipated into the water table underlying the beach. Where such a structure is employed it is important to provide a surcharge facility so that flows beyond the structures dissipating capability can be catered for. An example of this type of structure is an upright chamber with a grated opening at the top to allow for surcharge and an infiltration trench or rubble rock base to allow dissipation of water into the beach. Consideration must be given to managing the scour should a surcharge occur. In its simplest form this could be a rock rubble surround at the base of the upright chamber.

There are however two critical issues to be addressed before considering such a structure. The first is as to whether the discharge of stormwater into the beach water table will result in uplift pressures that will enhance beach erosion (the “quicksand effect”). The second is as to whether the underlying substrate is sufficiently permeable to avoid piping failures. Where there is an impermeable substrate immediately below the unconsolidated sand, such as an indurated sand layer or an underlying clay base, upwelling through the beach may occur with the resultant formation of a scour channel across the beach immediately in front of the structure. Because the discharging water will find the shortest path to the sea, the scour channel may make the structure more vulnerable to wave attack and may enhance beach erosion in its vicinity.

Water quality

By their very nature stormwater systems tend to convey suburban and non-urban detritus to the coast producing concentrated points of pollution discharge onto beaches or into the near shore coastal zone. The pollutants may take the form of floatables such as paper, plastic or wood. They may also be comprised of suspended material such as sediments and other matter including nutrients. Of more concern the stormwater may transport restricted substances picked up from roads, factories, or chemicals used in crop and weed spraying.

Often stormwater also conveys pathogens and viruses, which is a principal reason people are advised against swimming in the surf for at least 3 days after rainfall. The theory being that surf zone processes, the natural chemicals in sea water and exposure to sunlight will disperse and or kill pathogens and viruses within that 3 day time frame.

While during rainfall events and immediately after them the water quality issues relating to stormwater are generally recognized, there is a more insidious danger. Groundwater infiltration may continue to convey pathogens and viruses into systems for some weeks after rainfall events. In addition there is also a tendency for vermin to live in and around stormwater systems during ostensibly “dry” periods. Hence it is not unusual to find that testing of the residual “dribble” from systems during dry periods produces alarmingly high levels of pathogens and viruses.

It is in the nature of small children that they are attracted to shallow pools on a beach. Hence, where a stormwater pipe discharges onto a beach and, during a relatively dry period a resulting pool is formed on the beach berm, it is like a magnet with children choosing to play in the apparent safety of that pool rather than face the perceived more dangerous environment of the shore break. The health risks associated with this very natural behavior is often not recognized, nor signposted.

Equally, on some beaches the stormwater has been piped to the rock shelves at the ends of the beach in order to minimize beach scouring and the adverse visual impact on the beach amenity of a pipe outfall. Historically rock shelves have often provided the opportunity for councils to construct swimming pools for the beach going public. Without realizing the danger, councils have therefore diverted potentially polluted flows, during both wet and dry periods, into the proximity of a facility that encourages intensive primary contact for the swimming public.

Unsewered areas

In unsewered areas rainfall infiltration progressively waterlogs the ground flushing out residual pollutants, such as pathogens and viruses, principally from septic tanks or similar systems thereby making them available for transport by surface runoff or discharge into stormwater systems through groundwater movement. If the rainfall period has been of an extended nature then the polluted groundwater discharge may continue for days if not weeks after the rain has ceased and may enter the stormwater system directly as seepage into channels or creeks, or may infiltrate the system through breaks in pipes or open joints.

Sewered areas

In sewered areas, extended periods of rain, or at times of high rainfall intensity, the sewerage infrastructure can become stresses, particularly where development intensification has occurred; uncontrolled sewage discharges may be experienced. Most sewerage systems are designed to have relief overflows, particularly near pumping stations. In addition, where excessive amounts of stormwater have infiltrated the sewerage infrastructure, discharges can occur at manholes producing overland flow that usually finds its way to the most convenient stormwater system.

Where developed areas are in potential slip country and/or there are large trees, sewerage lines are vulnerable to breakages thereby releasing sewer into the surrounding soil and thence into stormwater systems.

Non urban and developing areas

In farming areas and disturbed lands such as building sites rainfall runoff, depending on rainfall intensity and volume, can entrain and transport considerable quantities of sediment into stormwater systems. Agricultural chemicals and, even in developed areas, weed management chemicals are often concentrated in stormwater discharges. In sewered, unsewered and non-urban areas overland flow from rainfall runoff can convey animal feces into stormwater systems.

Minimizing water quality issues

Stormwater systems can often result in potential dangers for both human and environmental health. It is important to recognize and address the minimization of these risks. Firstly, educate the public on the risks and how to avoid them by providing adequate signposting. Secondly, take every opportunity to divert discharge points away from popular public areas. Thirdly, where practical, seek to intercept the low to medium flow stormwater before it reaches the coast with either, or both, SQIDs and artificial or natural wetlands in order to remove as much of the pollution load as possible, including the nutrients and pathogens.

While it may be desirable to intercept the high flows this is seldom practical. They therefore need to be by-passed away from natural or artificial treatment systems to minimize the potential for damage to those systems and/or the unintended release of previously trapped nutrient and sediments. Regardless of the regularity of maintenance programs, most artificial and natural treatment systems are susceptible to the build up of pollutants, and uncontrolled or unintended flushing of these systems can result in the release of high concentrations of those pollutants. Some treatment of high flows may be possible by, for example, removal of coarse material with trash racks provided the trash racks do not become flow impediments and create additional problems.

Attention to source control, that reduces pollution, and increased public awareness of the risks and the natural dispersion and dilution processes of the ocean, are all-important weapons in managing health risks associated with high flow situations.

In situations where it is not practical to intercept the low flows, and the stormwater infrastructure discharges at a beach, consideration should be given to incorporate a flow-splitter that harvests the low flow situations prior to discharge but allows the high flow events to pass directly to the outfall. The low flow component can then be diverted to a dispersion pipe network located well below beach level thereby allowing the low flow to be filtered through the beach media hence simulating the behavior of a sand bed filter; a standard method of water treatment. This helps overcome the “puddling” on the beach berm or the polluted low flow discharges in the vicinity of swimming pools.

Changes in relative sea level

Because of the often low relief of coastal plains, stormwater systems associated with back beach developments are particularly susceptible to changes in relative sea level. The subsidence of coastal lands, or rises in sea level due to climatic change and/or storm surge from increased storm, can result in backing up of stormwater systems thereby rendering them less effective in managing flooding. Where this occurs it may be necessary to re-design or divert the stormwater infrastructure to re-establish sufficient gradient/capacity to enable the stormwater to be conveyed to an alternate receiving body.

In extreme cases it may be necessary to consider implementing a system in which the normally gravity based flow is replaced by high volume, low head, pumps such as the propeller type pumps typically used in irrigation areas. Discharge points must be fitted with gates to prevent oceanic back flooding.

Opportunities

Stormwater can be an important resource and hence the emphasis in recent times on Water Sensitive Urban Design principles. The application of these principles to both new and existing developments in the coastal zone can significantly reduce the volume of stormwater arriving at the coast and improve its quality.

The re-development of Warriewood Valley in the Pittwater LGA provided the opportunity to apply the principles of WSUD with emphasis placed on rainwater capture, rainwater detention, water quality management and aquifer re-charge. This was not only on a house-by-house and street design basis but also on the totality of the overall drainage systems of the Valley. Existing piped drains and channels were removed and replaced by constructed creeks that, through the developer contribution scheme, had associated 50m wide creek line corridors. The creeks were lined with geotextiles and then stabilized with rock armour consisting of 1 to 2 ton sandstone. The rocks were placed in a dry pack format to encourage seepage into the groundwater table, air entrainment through turbulent flow and gaps for plants and fauna.

The creek line corridors were planted out with native shrubs and trees and a range of artificial wetlands and detention ponds were incorporated into the overall system. These acted to limit the maximum flow rates, they also provided for nutrient and sediment stripping and opportunities for groundwater recharge rather than direct discharge through Narrabeen Lagoon to the ocean.

In total more than 6 km of creek were constructed along 3 different drainage paths with more than 2 ha of detention basins which also doubled as parkland and incorporated both nutrient and sediment stripping features. A number of gross pollutant traps were incorporated into the street stormwater capture system. The net result was a significant reduction in both the volume and pollution level of the stormwater reaching the coast through the mouth of Narrabeen Lagoon.

Of equal benefit was the substantial re-establishment of native forest along the creek line corridors and in the parkland as well as the low water demand of the houses due to both direct water capture but also significantly through aquifer re-charge. The lack of plastics, paper and other suburban detritus entering Narrabeen Lagoon along with the abundant fish life now populating the lower reaches of the main creek are testament to the success of a source focused, risk managed, coastal stormwater system.

Salisbury in South Australia provides another interesting example of a council that has taken aquifer re-charge further by capturing stormwater in ponds and wetlands where the water quality is managed and then the water is pumped down into underlying cracked rock aquifers. During dry times the pumping system is reversed and water is extracted from the aquifer to provide water for parks and gardens.

A common problem facing coastal councils is not only the stormwater from building development but also that generated by roads, car parks and parkland immediately behind the beach. Often this is captured in drainage systems and piped directly onto the beach, or the adjacent rock shelves. Although the total flow through such systems can be relatively small the instantaneous discharge rates can be high. Further they can deliver unwanted pollutants direct to the beach/surf zone, however the fitting of stormwater quality devices can significantly reduce this problem.

Rather than discharge these flows onto beaches, it is often possible, and preferable, to use the stormwater to recharge the aquifers in the dunes. This not only overcomes potential beach/dune scour problems but also enhances the opportunity to stimulate and maintain healthy dune vegetation cover.

Dune aquifer recharge systems can be deceptively simply constructed. Rather than directing road and car park drainage into stormwater systems, the stormwater can simply be allowed to flow across ground into shallow grassed depressions that have been sized to cope with the expected runoff volumes and are sited in parkland, underlain by sand, at the rear/top of dunes. These depressions “flood” during heavy rainfall when the parkland is not being used but quickly drain to the aquifer soon after the rainfall event. Examples of where the road/car park drains which previously scoured beaches and creek banks have been successfully diverted into aquifer re-charge depressions with long term benefit are at Palm Beach, Mona Vale Beach and Winnererremy Bay in Pittwater LGA.

In other locations such as Long Reef and Dee Why car parks in Warringah the stormwater has been successfully diverted away from the beach and into Dee Why lagoon through pipe systems that discharge into the surrounding wetlands. It finally makes its way to sea during the intermittent breakouts of the lagoon.

Where there are deep-water sewerage outfalls the opportunity exists, provided there is capacity, to utilize these outfalls to convey at least the often-polluted low flow component of stormwater well offshore. Sewerage outfalls will generally not have the ability to deal with high stormwater flows as at such times they are often operating at full capacity. Therefore, if the opportunity exists to divert a stormwater system to a sewerage outfall the stormwater system needs to be provided with a flow-splitter that allows high flows to be diverted to an alternate discharge structure.

These are but a few examples of the many uses of stormwater or at least its diversion away from direct, adverse, impact on beaches and beach users.

Summary

Stormwater presents a challenge for coastal managers. Poorly handled it can result in beach scour, enhanced beach erosion and both water quality and health issues. Well managed its adverse impact on beaches can be minimized and it can provide a resource for aquifer re-charge and hence enhanced dune protection and "drought-proofing" of back-beach parkland.

Aquifer re-charge generally involves the construction of subtle systems that tend to suffer from neglect as a result of corporate memory loss from the organization charged with their on-going maintenance. Carefully constructed detention depressions can, over time, get filled in because the managing body has forgotten their function and just sees them as depressions that need to be drained. That is they often eventually suffer the same fate as many other "soft engineering" solutions of being neglected or actively re-engineered into "hard solutions".

Where aquifer re-charge is impractical then opportunities should be pursued to re-direct stormwater to natural systems such as rivers, creeks and estuaries while at the same time taking care to minimize pollutants and manage velocities. If there is no alternative but to discharge into coastal embayments it is preferable to direct stormwater outlets to rock shelves, provided there is not an associated health hazard.

Finally, if there is no other option cross-beach discharge may have to be considered taking care to address issues of erosion, potential choking, impact on coastal processes and the structural adequacy of any engineering works. Remember however that cross-beach stormwater systems invariably fail at the very time they are most needed.

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