EVALUATION ON THE EFFECTS OF CLIMATE CHANGES AND IMPLEMENTED POLICIES ON MODERN MUSCAT CITY-OMAN

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ABSTRACT

Muscat is a coastal, well-ordered, and immaculate city in Oman. Muscat is featured by sharp steeped topography of dry rocky mountainous area with flat plains and valleys. The built-up areas of the city had to take place in valleys and on swales connected by main linear artery. This physical location makes the city exposed to be affected by global climate changes presented by heavy rain and cyclones. The heavy seasonal rains, floods and cyclone (Gonu-760 km/hr) recently left swathe destructions in these low lands. The floods always cause serious damages to urban elements, amenities and infrastructure. However, planning authorities, ministries, and urban development administrations developed policies, strategies, and technical guidelines to cope with such climate changes to maintain the sustainability of urban Muscat. The paper will present the effects of such changes on urban Muscat, and discusses the proposed policies, strategies and guidelines on the ground to tackle effects of climate changes. Furthermore, design and construction guidelines will be proposed to minimize such destructions.
Key wards: Climate Changes, Topography, Heavy Rain, Flood, Impact of policies.

1- INTRODUCTION:

Oman is one of the world's top 10 environmentally committed countries and is party to international agreements on biodiversity, climate changes, desertification, endangered species, hazardous wastes, marine dumping, law of the sea, whaling and ozone layer protection. Various organizations have formed to protect the environment as well as to educate the people on the importance of environmental issues (Explorer Team, 2006). Despite such efforts there are still some serious threats to the environment facing the sultanate, some of these threats are floods and water storms as results of climate changes.

Figure 1: Governorate of Muscat (from google earth)

The governorate of Muscat is the most densely populated region in the Sultanate with a population of more than 632,000, spread throughout six districts - Muscat, Mutrah, Bausher, Seeb, al Amerat and Quriyat (Figure 1). It is Oman's political, economic and administrative centre. Situated on the Gulf of Oman, it extends from Seeb, home of the country's modern international airport, in the north, to the fishing port of Quriyat, in the south (Ministry of Information, 2006).

The paper will present criteria and classifications related to the case and effects of climate changes on urban Muscat, the governmental acts to these effects as standards and criteria, the paper will also propose design and construction guidelines and practical solutions in addition to planning and urban design considerations, and finally, this paper will discuss and investigate the urban solutions in terms of urban functional and urban aesthetic proposals for urban Muscat.

2- PHYSICAL TOPOGRAPHICAL FEATURES OF MUSCAT

The Sultanate of Oman, with an area of 309,500 square kms, /encompasses a diverse range of topography, including mountain ranges, arid deserts and fertile plains. Oman lies on the Tropic of Cancer in the extreme southeast corner of the Arabian Peninsula, covering an area (between latitude 16.40 and 26.20 degrees north and longitude 51.50 and 59.40 degrees east), of major strategic importance.
The country's breathtaking coastline stretches for over 1,700 kms, from the Arabian Sea and the entrance to the Indian Ocean at its south-western extremity, to the Gulf of Oman and Musandam in the north, where it overlooks the Strait of Hormuz and the entrance to the Arabian Gulf; a location that has played a vital part in Oman's strategic development.

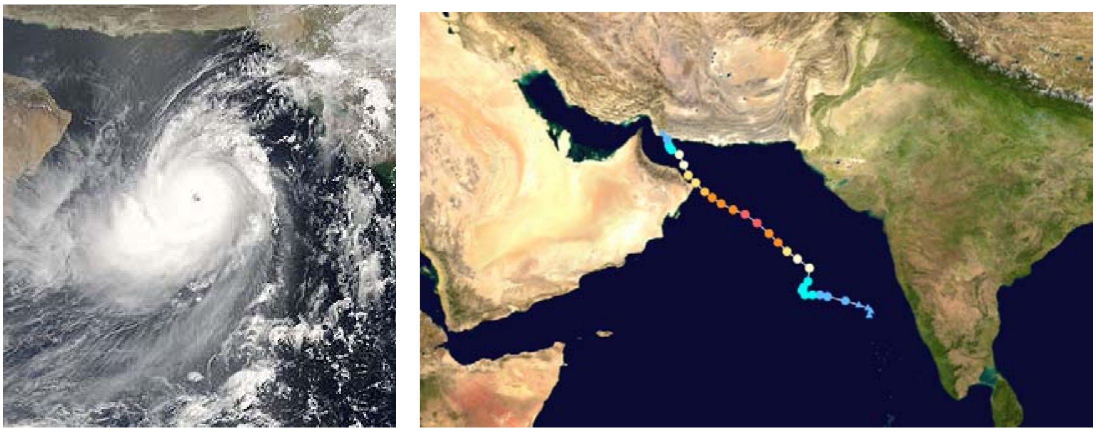
Figure 2: Topographical features and built-up area of Muscat (Inceruh, C. 2009)

Muscat is situated on the coastal plain of Oman. The Geography of Muscat is largely influenced by the coastal region which runs from As Sib to Ras al Hadd and is about 175 km long. It is barren and bounded by cliffs almost entirely along the length of the coastline. It is featured by sharp steeped topography of dry rocky mountainous area with flat plains and valleys. The built-up areas of the city had to take place in valleys and on swales connected by main linear artery (Figure 2). The hills are mostly unfertile but the plateau is arable where oases are present with the main streets lined by trees and traffic circles decorated by beautiful flowers that make the so called desert a green valley (Figure 3).

Figure 3: Main Street of Muscat, the green valley (SCCP, 2007: 58)

3- CLIMATE CHANGES IN MUSCAT

The country's climate, like its topography is diverse, with humid coastal areas and a hot, dry desert interior. Generally it is hot and humid during the summer, with temperatures reaching 48°C during the day in June and July, and averaging about 32°C at night. Humidity can rise to an uncomfortable 90%. The mean summer temperature in Muscat is 33°C (Table 1), but the 'gharbi' (western) wind from the Rub Al Khali can raise coastal town temperatures by another 6°C to 10°C. Average annual rainfall in the Muscat area is 75mm, while in some cases it reaches 700mm (Ministry of Information, 2006). Upon first forming, the system contended with the entrainment of dry air to the northwest of the storm, which was expected to limit intensification (Typhoon Warning Center, 2007). The storm steadily intensified, and early on June 2 the IMD upgraded it to deep depression status (Richard S.J. 2006). Later in the day the IMD classified the system as Cyclonic Storm Gonu about 760 km (470 mi), and an estimated pressure of 920 mbar (unit of pressure). Cyclone Gonu crossed the eastern-most tip of Oman



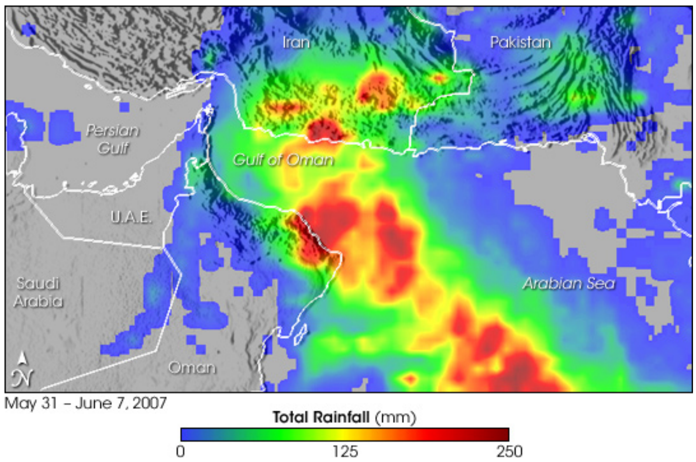
(Figure 4).

Figure 4: Cyclone Gonu near peak intensity (Wikipedia, 2007, & Wikipedia Commons 2007)

Due to its geographical location in the south eastern side of the Arabian Peninsula, the Climate in Muscat, the capital of Oman, is extremely hot and dry most of the year. Summer begins in mid-April lasting till October. It is extremely hot in summer, with coastal temperature moving up to 46 °C. The temperature in the interior areas is even higher. The mean summer temperature of Muscat is 33 °C. Due to its low elevation, it is hot and humid in summer, with humidity going up to 90 percent. Winter is pleasantly warm and mild during the months from October to March with temperature ranging from 15 °C to 23 °C. The climate of Muscat is influenced by the precipitation, which range from 20 to 100 millimeters a year. Sometimes summer winds are formed in the interior of Oman which is a threat to shipping in the south (TUI Travel PLC, 2009).

4- DESTRUCTIVE EFFECTS OF CLIMATE CHANGES ON URBAN MUSCAT

Near the northeastern Oman coastline, Cyclone Gonu affected the country with rough winds and heavy precipitation (Sunil Vaidya, 2007) with rainfall totals reaching 610 mm (24 in) near the coast (Daily News, 2007). Gonu produced strong waves along much of the coastline (Figure 5), (Sunil Vaidya, 2007) leaving many coastal roads flooded (Figure 10) (Saeed Al-Nahdy, 2007). Strong winds knocked out power and telephone lines (Figure 6) across the eastern region of the country. In Muscat, winds reached 100 km/h (62 mph), leaving the capital city without power. Strong waves and heavy rainfall flooded streets and some buildings (Figures 9 & 10). The storm water flooded commercial areas and shopping malls at Qurum, Muscat (Figures 8 & 9). In effort to prevent electrocutions, police workers sent text messages to residents which recommended residents away from certain streets.



Seas lash the Mina al Fahal rock in Qurm, Muscat.

Figure 5: Rainfall, exceeded 200 mm, Gulf of Oman May 31 - June 7, 2007. (TWC, 2007)

Figure 6: Strong winds knocked out power and telephone lines (CAE, 2007)

Figure 7: A torrent of water crashed through roads, housing and gardens (CAE, 2007)

According to the Oman News Agency, the cyclone killed 49 people in the country, with an additional 27 reported missing by four days after it struck the country (Associated Press, 2007). Around 20,000 people were affected (Associated Press (2007), and damage in the country was estimated at around $4 billion USD, in 2007.

Figure 8: The Qurm shopping area in Muscat. (CAE, 2007)

Shopping malls at Qurum, Muscat

Residential buildings & streets at Qurum, Muscat

Figure 9: Heavy rain flooded urban streets and buildings in Muscat. (CAE, 2007)

Figure10: Destructive effects of storm floods at Muscat (CAE, 2007)

5- GOVERNMENTAL RESPONDS TO THE CLIMATIC DESTRUCTIVE EFFECTS IN URBAN MUSCAT

The Oman Chairman of the National Committee for Civil Defense remarked the nation had already developed a contingency plan, especially in northeastern areas, along with up to 150 mm (6 in) of rainfall (Figure 11) and very strong winds (Typhoon Warning Center 2007).

The Ministry of Information was among a number of bodies singled out for their sterling efforts in the face on the cyclone. The Ministry was praised for its exceptional achievement in keeping people aware of events; anticipating new areas of concern and constantly coordinating with the relevant services on the ground to make sure information was disseminated swiftly and efficiently. Television and radio stations launched around-the-clock services, supported by the tireless efforts of presenters and engineers to keep the viewing and listening public abreast of events. For planning and future considerations, the supreme commission of city planning in Muscat has defined the flood regions under three categories in terms of event/year, where each has its own criteria in planning and design issues. (SCCP, 2007: 19-20):

1. Frequently flooded regions (one year flood events)
2. Mediam flooded regions (6-years flood events)
3. Rarely flooded regions (21-100 years flood events)

Figure 11: Flood region in Muscat. (SCCP, 2007: 21)

The commission also classified the floods, in Oman, in terms of their dangerous effects into three main regions, (SCCP, 2007: 20-21):

1. Highly dangerous flooded (more than1m water level with speed of 2m/sec.)
2. Median dangerous flooded regions (up to1m water level with speed of 0.5m/sec.)
3. Low dangerous flooded regions (less than1m water level with speed of less than 0.5m/sec.)

5.1- Guidance to Protect Urban Areas:

The Ministry of Water Resources, in Muscat, had developed flood-standards/instructions for each flood area in Oman (especially in Muscat, Salala, Nizwa, Sohar, Deba, etc.). Thus, the Ministry used these standards in preparing the master plan of cities according to the above mentioned regions of flood classifications. However, the planning in charge organizes building areas after getting the approval from the Ministry of Water Resources, by using the plans with their urban requirements in the decision making of the urban land-use proposals. (SCCP, 2007: 21-22)

5.2- Building Construction Requirements in Flood Regions:

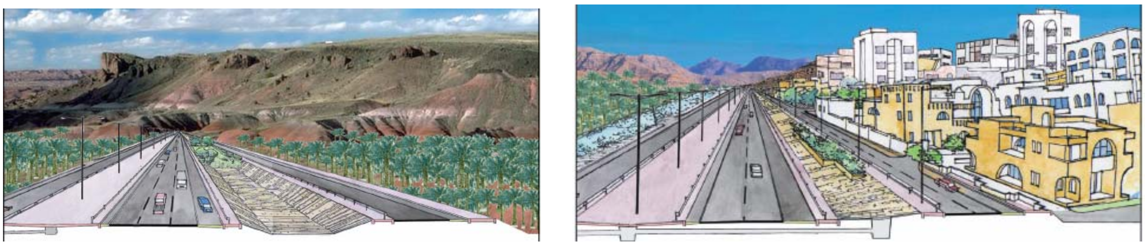
For any building construction in flood areas, in Muscat, engineers have to make precise study on construction documents, with relations to plans and reports provided by the Ministry of Water Resources. Furthermore, construction drawing and details must be approved by the planning authority for technical revision, where building's construction and extension are not allowed in highly dangerous flood regions. However, in these regions, construction can be realized under seven conditions and requirements:

- **1st Building Requirement**: Providing no permission for construction within regions of highly and median dangerous flood, unless government provides protections from floods.
- **2nd Building Requirement**: The building construction materials must be of flood resistant capacity and shall be used according to the law and documents of local municipalities' construction specifications.

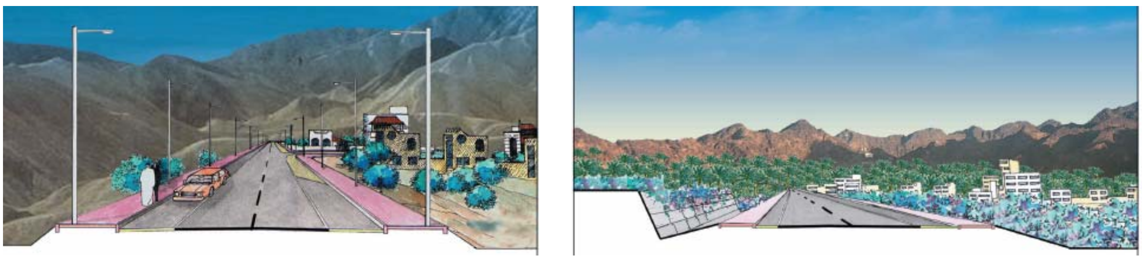
- **3rd Building Requirement**: The basement of all new buildings must be raised up to 0.5 m above flood level.
- **4rth Building Requirement**: If building construction is in the flood area, the owner/contractor must make modifications on land to avoid the increase in flood level.
- **5th Building Requirement**: If building project is within the range area of flood, the owner/contractor must prove by documents that his building can stand against the flood and the flowing water drifting stones and other materials.
- **6th Building Requirement**: In case of building within the flood area, the owner/contractor must prove by documents that the building will not increase the danger of the flood.
- **7th Building Requirement**: In case of building within the flood area, the owner/contractor must guarantee and provide all technical means to evacuate the building, in the right time, to the planning authority.

5.3- Road Construction Requirement:

The supreme commission of planning, in Oman, developed road construction criteria to avoid the expected and unexpected floods, by using cut-and-fill method. Thus, all roads, streets and highways in flood regions are subject to construction criteria (SCCP, 2007: 130-143) The following examples in Figure 12 are good examples, of many, that show the details of this method.



Half road section of 120m & 80m width, height of 1.5m-3m



Local road section of 30m width, and height of 1.5m

Figure 12: Water storm flood considerations in roads constructions (SCCP, 2007: 130-143)

5.4- Surface Water Drainage Control

The Ministry of Regional and Environmental Municipalities assumes the construction and maintenance of all means and elements of surface drainage systems in all Oman except Muscat, where the municipality of Muscat do this job.

All urban regions, in Muscat, are provided with surface drainage systems (Figures 13 and 14) connected with regional surface drainage to be drained into the nearest valleys. However, the

Ministry of Regional and Environmental Municipalities developed criteria for surface drainage systems in urban areas including Muscat (Figures 13 and 14):

a- surface channels along service rods
b- underground pipes and channels along or across local roads
c- secondary roads work as surface drainage channel

Stream-flow in arid and semi-arid regions tends to be dominated by rapid responses to intense rainfall events. Such events frequently have a high degree of spatial variability (Croke,B. & Jakeman, A.J)

Figure 13: Surface Drainage in urban and regional Muscat. (Inceruh, C. 2009)

Figure 14: Surface underground and along road channels in urban Muscat (Inceruh, C. 2009)

5.5- Procedures of flood control:

An objective assessment is also being made of the lessons that might be learned from the tragedy, so that preventive measures, such as defensive dams (Figure 15) can be put in place; these additional measures will complement the groundwater. Nevertheless, the Ministry of Regional and Environmental Municipalities developed three main procedures to control flood in urban Oman:

- a- To drain peak flow of storm water during flash flood, valleys and drainage channels are enhanced
- b- To prevent flood water from reaching specific areas in buildings, by elevating building levels
- c- To control peak flow to levels that can be drained safely into drainage channels, storage basins are maintained

Figure 15: Defensive dam in Muscat. (SCCP, 2007: 204)

6- PROPOSED DESIGN AND CONSTRUCTION GUIDELINES AND PRACTICAL SOLUTIONS

As noticed in part 5, the Ministry of water resources and the supreme commission of planning in Oman did not define precisely numerical values and standard-dimensions to drainage facilities, they did not, also, clarify the minimum full detailed requirements to conveyance facilities, and the design procedures, at both urban and street scale, were not defined to determine the best management projects (BMPs) implemented on construction sites. Therefore, we can get benefit from the experiences of United States of America in this subject; by using the criteria, standard-dimensions and design procedures in both the "*City Of Oakland Storm Drainage Design Guidelines*" (COSDDG, 2006), and the "*Storm-water Quality Handbooks of California*" (SQH, 2007)

6.1- Drainage Facilities

Protection and analysis of the City's drainage system are categorized by the tributary areas. The City considers three categories of natural and improved drainage facilities (COSDDG, 2006):

1. Major Facilities: Such facilities are waterways with tributary areas equal or larger than 64.5 Square kilometer such as the San Leandro Creek and other major waterways that are primarily maintained by the County Flood Control District.

2. Primary Facilities: Such facilities are waterways and drainage facilities with tributary areas between 20 hectares and 64.7 square kilometers. These facilities mostly consist of creeks and larger improved waterways and drainage facilities. Many of these facilities are owned and maintained by the Alameda County Flood Control District.

3. Secondary Facilities: Such facilities are drainage-facilities or waterways with tributaries areas less than 20 hectares. This includes majority of the City's drainage conduits.

- Other lining materials shall be investigated by the engineer for the proper roughness and geometry. For open channels and closed conduits, the n-value may vary depending upon construction methods, maintenance procedures, and materials involved
- Debris and sediment basins may is required in the design of certain drainage control facilities and the need for such structures shall be determined on a site-by-site basis.

6.2- Conveyance Facilities Minimum Requirements

Minimum pipe size shall be 30 centimeters in diameter and the pipe materials for buried pipe installation shall be RCP class III or HDPE SDR 11 minimum. Pipes shall not decrease in flow cross sectional area or diameter in the downstream direction.

Minimum bottom width for open channels with established vegetated bottoms and sides shall be 120 centimeters. For these channels, the ratio of side slope shall be no steeper than two and one half (2 1/2) horizontal units to one (1) vertical unit.

Minimum bottom width for improved channels (concrete or paved) shall be no less than 60 centimeters and the side slopes shall be no steeper than one (1) horizontal to one (1) vertical for concrete, and two (2) horizontal to one (1) vertical for reinforced earth with vegetation.

Access manholes or access structures for underground storm drainage conduits shall not exceed 122 meter on center. Inlets are considered access structures (COSDDG, 2006)

6.3- Storm Water Detention

A. Parking lots shall provide pedestrian access through the ponded areas. Depths of ponding shall not exceed 10 centimeters.

B. Conduit storage can be utilized by oversizing the underground drainage facilities. Care should be taken to prevent siltation problems.

C. Channel storage can be utilized by oversizing open channel facilities. Care again should be taken to prevent siltation problems, and allowances must be made for a minimum capacity at a maximum silt buildup.

D. Multi-purpose facilities can be used as detention facilities such as park areas, tennis courts, parking areas, existing ponds and wetland areas, and landscaped areas.

E. The detention pond shall be designed such that the water surface returns to its base or starting elevation within 24 hours after the cessation of a 24-hour, 100-year storm.

F. Detention basins shall be designed to store urban runoff from sites such that the post-project discharge rate is maintained at a rate less than or equal to the pre-project peak discharges.

G. To the extent possible, for single-family home site development or lot improvements, the City requires a net runoff coefficient of 0.25 from the entire site. Builder and developer are encouraged to employ BMP measures and concepts such as Bioretention, Swales, Pervious Pavers, Rain Barrels, Cisterns, and Tree Wells as some of the commonly used methods to reduce stormwater peak flows.

H. The 15- and 100-year existing conditions peak discharges must be calculated and future conditions runoff hydrographs, for this flood events, must be developed.

I. The required detention basin storage must be calculated and determine the volume in the future conditions runoff that exceeds the existing conditions peak discharge.

J. Consider that some modifications require permittees to implement specific sampling and analytical procedures to determine if BMPs implemented on a construction site (SQH, 2007) are:

a- Preventing further impairment by sediment in stormwaters discharged directly into waters that impaired sediment, silt, or turbidity. And

b- Preventing other pollutants that are known or should be known by permittees to occur on construction sites and that can not be visually observed or detected in stormwater discharges, from causing or contributing to exceedances of water quality objectives.

Finally, an Information Handout must be prepared to provide a list and/or written descriptions of existing pre-construction control practices (BMPs) that are already in place to reduce sediment and other pollutants in storm-water discharges.

6.4- Investigation of Planning and Urban Design Considerations

Residential and commercial development has profoundly impacted natural drainage ways throughout Muscat area. Development projects are responsible for planning, designing and constructing a large portion of the major drainage infrastructure. Successful implementation of Urban Drainage and Flood Control District master plans is essential in promoting the long-term stability. Thus, master planning program starts at the inception of a district (Mallory, D. 2001) with a set of questions and related answers, as follows:

a. Can subsequent development projects rely on the proposed master plan hydrology? Not necessarily, some formalization of the proposed detention ponds is needed in order to recognize attenuated flows. Because, we do not recognize inadvertent detention unless the master plan provides for a regional detention pond at the site in question and some formalization has occurred.
b. Does development occur in a vacuum or unilaterally? Onsite or local area detention ponds must be designed for their entire tributary watersheds, where onsite detention ponds situated within major drainage-ways.
c. Are regional detention ponds identified in the watershed master plans? Locating a regional pond on a specific property in a master plan is not enforceable. But planners have to work with developers and local governments to incorporate regional detention into projects in accordance with the published master plan.
d. Does District always support the concept of leaving flood plains in their natural condition? Urbanization dramatically increases the volume of runoff, which in turn accelerates the natural degradation process. Therefore, stream stabilization through the use of grade control structures is generally required.

At urban scale, stormwater management must be a fundamental consideration in the planning and design of urban development. Unfortunately, it is often treated as a subsidiary issue that is not addressed until the final stages of the planning and design process. As Coombes, P. (2003) states that by considering stormwater management at the initial design phase it is possible to ensure viable stormwater management solutions that are compatible with other design objectives for the site.

The best way to take a 'whole site' approach is to prepare a Site Analysis. The site's topography will have a significant impact on the layout design. This is because stormwater drainage systems almost always rely on gravity. Topography will also affect runoff onto the site from surrounding properties. Existing overland flow paths should be identified and retained. Drainage easements, natural watercourses and flood prone land should also be identified and considered in the design process. Buildings must be kept clear of drainage easements to ensure public safety. Consideration also needs to be given to local soil conditions. Relevant factors include absorption capacity, erosion potential, soil salinity and the possibility of soil contamination from past activities.

The basic principle is to avoid adverse stormwater impacts on other properties. Therefore, careful consideration must be given to controlling surface runoff and subsoil drainage to adjoining properties. Fencing and landscaping should be designed so as to minimize the potential for overland flow paths. Whereas, the floor levels of habitable buildings must be designed so as to be above the expected water levels for overland flow paths, detention storages and flood prone land. However, The main objective is to collect and convey stormwater to the street drainage system with a minimum of nuisance, danger or damage. Roof runoff is discharged via small diameter pipes, and surface stormwater can be conveyed by overland flow. The public drainage system usually consists of a system of gutters, streets, pipes, culverts and channels owned and operated by the local council or other authority (Figure 14). Where the site slopes towards the street, roof runoff and overland flow are drained directly to the street drainage system.

According to Coffman,L.S. (2001), the most important features in urban design that drainage is fundamental to urban living, and flooding occur when the design fails. Therefore, techniques are based on the premise that stormwater management should not be seen as stormwater disposal. Instead of conveying and managing / treating stormwater in large, costly end-of-pipe facilities located at the bottom of drainage areas, stormwater must be addressed (Coffman,L.S. 2001). Almost all components of the urban environment have the potential to serve as an Integrated Management Practices (IMP). This must include not only open space, but also rooftops, streetscapes, parking lots, sidewalks, and medians.Therefore, the more techniques that are applied at both urban and street design levels, the closes we approach to maintain the sustainability and protection of urban Muscat.

Most of the 'paving over' in developed areas is due to common roads and parking lots, which play a major role in transporting increased stormwater runoff and contaminant loads to receiving waters. Alternative paving materials can be used to locally infiltrate rainwater and reduce the runoff leaving a site. This can help to decrease downstream flooding, the frequency of combined sewer overflow (CSO) events, and the thermal pollution of sensitive waters (Rushton, B.T. 2001). Use of these materials (Figure 16) can also eliminate problems with standing water, provide for groundwater recharge, control erosion of streambeds and riverbanks, facilitate pollutant removal, and provide for a more aesthetically pleasing site (Figure 16). Alternative pavers can even eliminate the requirement for underground sewer pipes and conventional stormwater retention / detention systems. The drainage of paved areas and traffic surfaces by means of permeable systems will be important to achieve a stormwater management system close to natural conditions.

Figure 16: Infiltration Permeable Pavers (Rushton, B.T. 2001: 4)

Water Sensitive Urban Design is a relatively new concept which aims to manage and conserve water as well as to resolve some of the problems caused by conventional urban drainage systems. There are many problems that may not be foreseeable both during the design stage (Khiadani, M & Beechman, S.C. 2007). It represents a more sustainable approach to water and stormwater management systems, and aims to minimize the impact of urban development on the natural water cycle. However, there are three different types of devices that can be applied to urban Muscat as part of urban projects, as permeable pavers:

1. "Gravel bed/trench units;
2. Porous pavers;
3. Atlantis Drainage Cell infiltration systems" (Khiadani, M & Beechman, S.C. 2007).

Furthermore, Admin, K (2008) developed another three types of permeable pavements. These types again can be proposed for urban Muscat:

1. Plastic pavers: A plastic honeycomb grid in which grass or other vegetation can grow.
2. Concrete pavers: Concrete blocks withspaces in betweenthem for better drainage.
3. Asphalt/concrete: Fine particles are left out of it to make it more porous.

These types are of common uses in Driveways, Emergency access lanes, Public parks, Alleys, Parking lots, and Bike or walking paths.

Finally Mccormack's (2009) infiltration paving systems can be added to above lists for better urban Muscat:

A- The Sub-Base Layer system: that acts as a reservoir, to provide storage for collected surface water and to release it to the natural environment at a controlled rate (Figure 17). Water percolates into the sub-base from the surface where it is stored and gradually released to main collector. It may be that the ground is clayey and slow-draining, or it is subject to events that involve large quantities of water, which brings us to "System B"...

B- Partial Infiltration System: The higher up the sub-base it is placed, the greater will be the quantity of water stored before overflow conditions occur (Figure 18).

C- No Infiltration System: none of the collected water is allowed to escape to the ground. It is good example when there is a risk of pollution and when rainwater harvesting is required. The permeable pavements are installed to be polluted or pollution-generating sites, allowing contaminated water to escape to ground would not be a good idea. In dry Muscat where rain-water represents a valuable commodity, and so it makes sense to retain collected water for use. In these No Infiltration systems, a collector pipe penetrates the tanked construction to allow water to be drawn off as required (Figure 18).

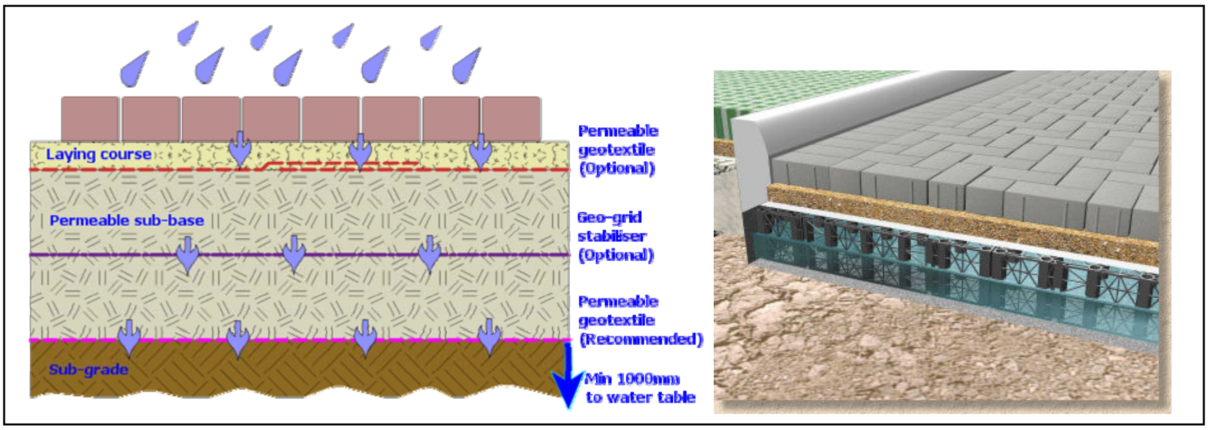


Figure 17: System A - Total Infiltration Permeable Pavement (Mccormack, 2009)

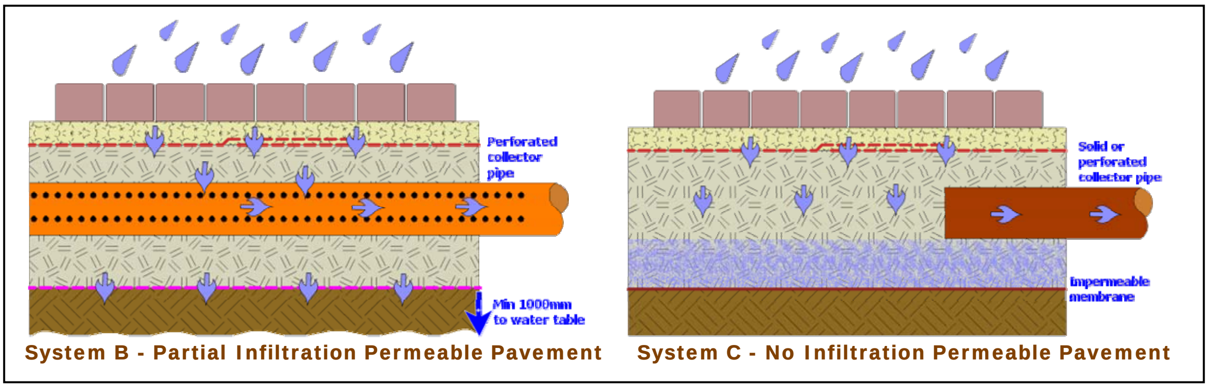


Figure 18: Partial Infiltration and No Infiltration Permeable Pavements (Mccormack, 2009).

For pavements that will be subjected to heavy traffic loads, there is the possibility of incorporating a permeable layer of bound material within the sub-base (Figure 19). This may be "hydraulically bound" (concrete to us mere mortals) or dense bitumen macadam (DBM). The concrete option is often referred to as a "No Fines Concrete" and is based on the same grading distribution and will have relatively low cement content, typically 3-10%. When DBM is used, it will need to be cored (or punched) at regular intervals to provide 'escape routes' for any trapped water, with the resulting holes filled with the coarse graded aggregate described above (Figure 19).

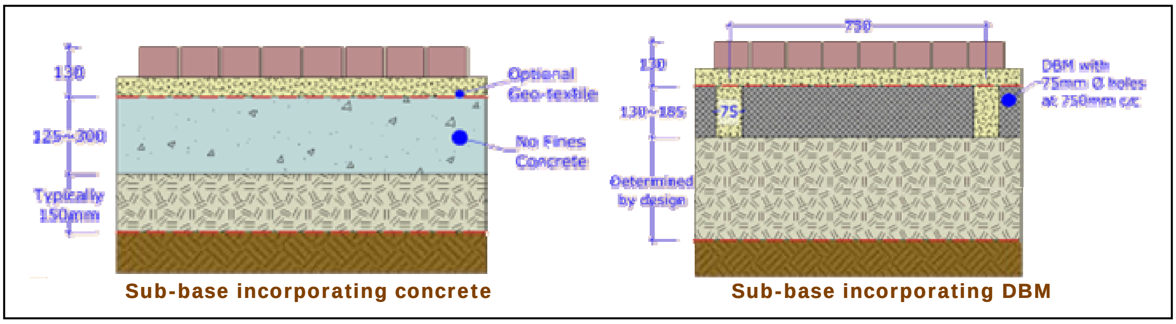


Figure 19: Sub-base incorporating concrete & DBM ((Mccormack, 2009).

6.5- Urban Design Aesthetic and Functional Considerations of Water Drain Systems

All surface water canals, drainages, channels, and canals must be considered as urban and landscape elements that must be designed for other purposes and functions to be part of Muscat city beautification activities. For examples, the regional and urban surface drainage crossing green parks can be designed as playgrounds, strolling paths, horse riding tracks, or jogging paths (especially those in figures 12, 13, & 14). Some others, urban linear elements (in figure 14), especially those along roads can be designed as side walks, roller-skater tracks, children play, and sitting and gathering linear areas, and some others can be designed as bicycle riding paths. All these proposals can be beautified with edge and shading plant materials to provide pleasant urban environment. However, their pavements can be considered with the urban contextual design order and system to attract urban population and to provide a coherent and integrated urban environment. Therefore, urban designers and landscape architects are all invited to handle the design of these linear urban spaces as their urban design and landscape systems (Figure 20). Thus, these linear spaces will sustain and maintain green arteries in urban Muscat, and also to take these urban spaces as accesses that connect the scattered parts of urban Muscat. Furthermore, the scattered quarters will be connected (by these urban spaces) via natural valleys to seashores and with urban green parks and historical sites to create a coherent green system in Muscat that may play important role in tourism and city recreational activities. Last but not the least these linear urban spaces will not be any more just a dry ugly leftover hard-paved elements penetrating Muscat city, but rather recreational and beautiful urban linear elements.

Figure 20: Multi-purpose urban activities and beautification in leftover spaces

7- CONCLUSION

The majority of stormwater runoff in urban area is from impervious surfaces such as roofs, paved areas and roads. Except in the case of major storms, little or no runoff occurs from pervious surfaces such as lawns, gardens and landscaped areas. Urbanisation has dramatically increased the area of impervious surfaces. This in turn has resulted in increased peak discharges and greater volumes of runoff per storm. The direct discharge of roofwater and overland flow to the street drainage system causes rapid and concentrated discharges of stormwater. This contributes to increased flooding, erosion and sedimentation, and reduced stormwater quality. These problems can be reduced by measures that delay stormwater discharges and that reduce the total volume of stormwater discharged.

The costs of climate change are expected to rise during the course of this century, but these costs will not be distributed uniformly or equitably. They will be most severe for the countries that can least afford them - the less-developed countries (LDCs) of the world's tropical regions, where higher mean temperatures and coastal flooding will have costly and potentially catastrophic effects on human life and social welfare (Smit, B. & Wandel, J. 2006).
However, climate change will not likely constitute a major threat to the overall economy of the country. Because Oman always responds well to environmental crises like Gonu Cyclone, or any heavy rain, but still efforts ongoing to cover lack of resources or incapability of national institutions.

The effects of climate change in Oman are not likely to be nearly as destabilizing as in the world's poorer countries. They rely predominantly on agricultural or other resource-based industries like tourism or fishing, all of which are highly climate-sensitive. This is especially true for poor countries in warmer climates, where the marginal effects of additional heating are likely to be greater.

Finally, there is reason for both optimism and pessimism about climate change in the twenty-first century. The bad news begins, of course, with the brute fact of climate change and the social costs it will likely entail. Those costs are already being felt, and they will multiply during the course of this century. Meanwhile, the near-term prospect for meaningful action on climate change appears bleak. The best climate change policy for all countries is to raise their per capita income by diversifying their economies and building more adaptively efficient institutions. As they grow wealthier, their capacity to adapt to the effects of climate change will increase.
Finally considering the surface drainage elements as urban and landscape elements will not threat us of making many of them.

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