SURFACE WATER DRAINAGE SYSTEMS TO MANAGE ENVIRONMENTAL CONSEQUENCES OF DEVELOPMENT: AN APPLICATION TO INDUSTRIAL ESTATE DEVELOPMENT IN SRI LANKA

by

N. T. S. Wijesekera

Abstract

Sri Lanka is fast moving into an era of rapid industrialization. One aspect of the government's industrial policy is the establishment of Regional Industrial Estates, which are to be well-designed and equipped with pollution control and properly-developed infrastructure facilities.

The Karanawanwatta site at Dankotuwa in the northwestern province of Sri Lanka, is one of the sites identified for development as an industrial estate.

As part of the effort to ensure proper infrastructure facilities for the industrial estates, it is important to foster environmentally-friendly sustainable development. The infrastructure development activities of the estate will change the land cover and the drainage pattern. Such changes increase the volume and velocity of runoff, creating less groundwater recharge and more erosion and higher peak flow during storms.

These changes affect natural streams and dug wells downstream from the site, and could also threaten the sustainability of flora and fauna in the riparian environment. Increased runoff coefficients due to the industrial estate development activities may result in rapid releases of stormwater, which lead to higher downstream flood levels and longer inundation periods than experienced prior to the development of the estate. These cause inconvenience and even direct harm to downstream occupants.

This paper describes simple, low-cost engineering solutions that were recommended to be incorporated in the development plan of the Karanawanwatta industrial estate to ensure mitigation of the environmental impacts of stormwater.

1.0 Introduction

Sri Lanka is fast moving into an era of rapid industrialization. Industry-based contributions have overtaken traditional agriculture-based exports in contributing to the Gross Domestic Product. Accelerating the economic development process through industrial development requires that more industries should be encouraged to generate more industrial exports. One aspect of the government's industrial policy is the establishment of Regional Industrial Estates, which are to be well-designed and equipped with pollution control and properly-developed infrastructure facilities.

One essential component of expanding industrial activities, is that siting of industries needs to be properly administered to prevent any unnecessary harm to the environment. With this goal in mind, the government has adopted a policy to require those who would be developing new high- and, medium-polluting industries to locate their factories within Ministry-approved industrial estates. The ministry of Industrial Development has identified a number of sites recommended by the Regional Industrial Service Committees (RISC).

The Karanawanwatta site at Dankotuwa (7° 18′ 48″N, 79° 53′ 52″E) in the northwestern province of Sri Lanka, with a land area of 23.5 hectares, is one of the sites identified for development as an industrial estate. Required environmental clearance for development has already been received by the

Eng. (Dr.) N. T. S. Wijesekera BSc Eng (Hons), M.Eng., PhD (Tokyo), C.Eng.,MICE, MIE (SL): Graduated from the University of Sri Lanka, Peradeniya in 1979. Worked at the Mahaweli Engineering and Construction Agency between 1979-1993. Obtained full professional qualifications in 1983. Presently a Senior Lecturer at the Department of Civil Engineering of the University of Moratuwa.

Ministry of Industries from the environmental authorities after the submission of Initial Environmental Examination (IEE) report on this site (NAREPP 1995).

As part of the effort to ensure proper infrastructure facilities for the industrial estates, it is important to foster environmentally-friendly sustainable development. The infrastructure development activities of the estate, such as construction of the internal roads, related drainage network, and buildings and boundary walls for industries will certainly change the land cover and the drainage pattern. Such changes increase the volume and velocity of runoff, creating less groundwater recharge and more erosion and higher peak flow during storms.

These changes affect natural streams and dug wells downstream from the site, and could also threaten the sustainability of flora and fauna in the riparian environment, due to stream bank and bed erosion and reduction of moisture levels in the subsurface layers. Eroded material from the estate surface resulting from altered landscape and land covers are likely to create siltation in the downstream paddy fields and water bodies. Increased runoff coefficients due to the industrial estate development activities may result in rapid releases of stormwater, which lead to higher downstream flood levels and longer inundation periods than experienced prior to the development of the estate. These cause inconvenience and even direct harm to downstream occupants.

This paper describes simple, low-cost engineering solutions that were recommended to be incorporated in the development plan of the Karanawanwatta industrial estate to ensure mitigation of the environmental impacts of stormwater.

2.0 Physical Environment

The site for the industrial estate **(Figure 1 and 2)** forms a small hill with two gradual slopes to the north and south. The present land use is primarily a coconut cultivation with substantial undergrowth. The rest of the area is covered with shrub vegetation. On the southern side a few hundred meters beyond the estate boundary, a small stream originating at the bottom of the slopes, drains to an irrigated paddy area. The site is roughly a rectangular tract with land sloping up to 1.4% downward to the northwest and southeast from a central hill. Water from both slopes drains to nearby paddy fields. There are no well-defined streams within the site.

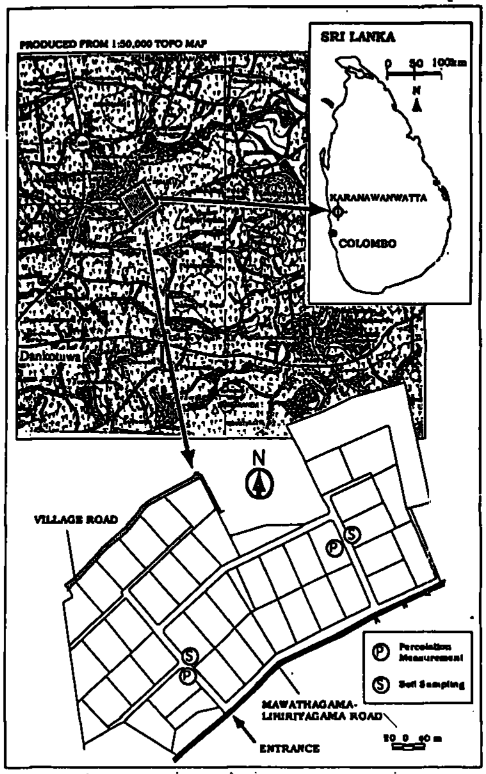

Figure 1: Location Map of the Industrial Estate and Test Sites

Site visits, excavated trial pits, field infiltration tests and laboratory soil tests done at the site during the initial environmental examination revealed that the site consisted of poorly-graded sandy clay. The region close to the hilly center consisted of soils with moderate permeability, while the rest of the soils had excellent permeability and excellent water-holding capacities (NAREPP 1995). Permeability and Soil test locations are indicated in **Figure 1.** The site is located within the wet zone of Sri Lanka, but close to the boundary of the wet and intermediate zones; as such it experiences an annual rainfall of only about 1850mm with the Maha (October - March) season receiving about 1025mm of the total. Location of the site, soil properties, and the present land cover and the streams in the vicinity indicate that the site substantially contributes as a recharge area for the groundwater aquifers in the region.

3.0 Stormwater Disposal

The development plan of the industrial estate, including the contours, blocking out of allotments, and internal road network is shown in **Figure 2.** The storm drainage network and related structures must be properly designed for the quantities of flow and located according to the site topography to ensure efficient passage of quantities of stormwater to the

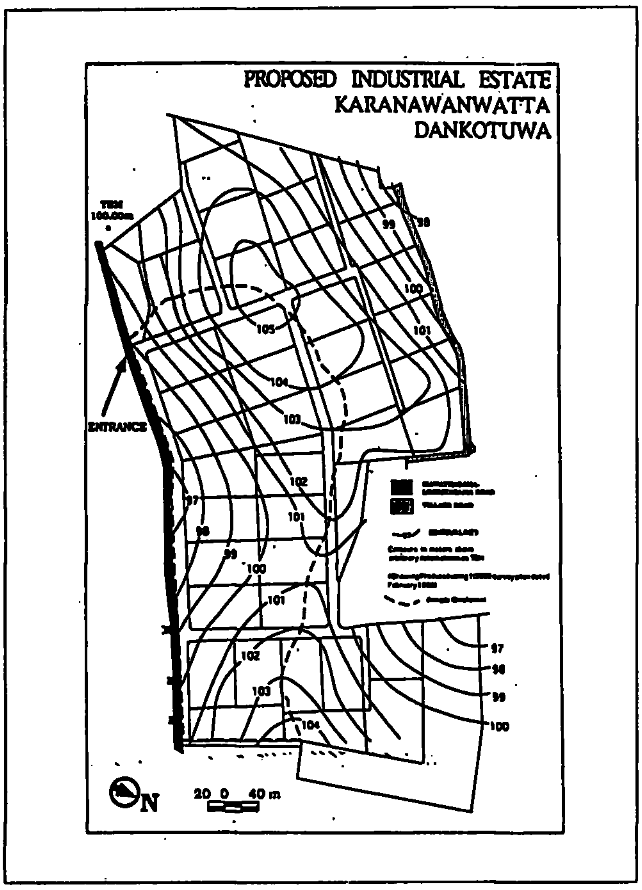

Figure 2: Site Topography and Blockingout Map

downstream regions. However, in order to mitigate the environmental impacts arising from stormwater runoff, the temporal pattern of stormwater from the estate should remain similar to that of the pre-development stage, with adequate infiltration taking place to maintain the moisture supply to groundwater aquifers.

Field visits were carried out in October 1996, to inspect the ongoing road and drainage-network construction works. The culverts that were already constructed to suit the road network and those that were subsequently recommended for entire coverage of stormwater drainage across the internal roads are shown in **Figure 3**. An examination of the layout maps and the field inspections revealed the necessity of detention/infiltration facilities to mitigate the changes in the temporal pattern of surface and subsurface runoff that arise as a result of development.

4.0 Design Investigation

In order to examine both pre- and post-development behaviour of the stormwater, a sample catchment area within the industrial estate was selected. The catchment draining to the existing culvert at the Mawathagama-Lihiriyagama road was treated as the sample watershed. Boundary of the said catchment is shown in Figure 2. A design storm with 2-year return period was adopted, considering that the proposed estate site is located at close proximity to a small city (Chow et. al 1988). A longer return period would ensure a higher level of safety, but would incur higher costs of construction and more space requirements for simple detention storage facilities. These factors were also considered in the determination of design storm.

Hydrological computations were carried out to investigate the volume of detention required for the anticipated surface interventions as a resulting from development activities.

2-year surface flows prior to the development were generated using a topographic map of the catchment and the synthetic unit hydrograph concept (Dept of Irrig 1980-1). Synthetic hydrograph parameters were based on the physical characteristics pertaining to the locality of the industrial estate (Dept of Irrig 1980-2). The concept of Modified Rational Formula (Chow et. al 1988) was used to develop the flood hydrographs for the before and after development scenarios. Critical duration of the design storm treating as the one requiring greatest detention storage was calculated using the variation in the difference of runoff volumes from before and after development conditions.

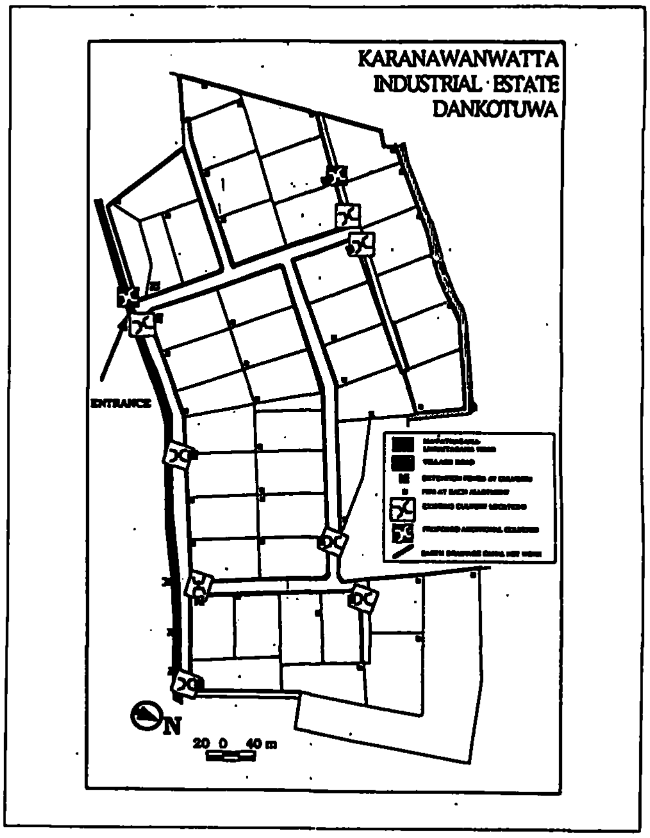

Figure 3: Drainage Canal Network Culvert Locations And Detention/infiltration Facilities

Table 1
Variation of Detention Volume with Runoff Coefficient for a 2-year Storm.

Runoff Coefficient	Critical Rainfall Duration (min)	Detention Volume cu. m/100 sq. m. in allotment area
0.75	36.5	0.33
0.80	42.0	0.55
0.85	47.5	0.79

Rainfall intensity-duration-frequency relationship of the region for storms with duration between 15 and 60 minutes was established using a curve fitted to the data of hydrological zone in which the site is located (Dharmasena & Premasiri 1990). Required detention volume for the anticipated land-use change, resulting a runoff coefficient around 0.8-0.85, was treated as the most appropriate case for this industrial estate. Variation of required detention volume per square meter of catchment surface area with changing runoff coefficient is shown in **Table 1.** After comparing the suggested values in the published professional literature and assumptions made in these computations (Schwab et al 1981, Chow et. a1 1988), along with land availability and prevailing construction facilities, the optimum detention volume was determined to be 0.7% of catchment area (square meter) to a depth of one meter for a 2-year frequency storm. The values obtained were based on a safety factor of 1.25 and an assumed post development runoff coefficient of 0.80.

5.0 Detention/Infiltration Ponds

In case of incorporating detention storages to arrest a flood hydrograph peak beyond the location of a particular catchment, the most effective solution is to provide the detention facility immediately upstream of the point of concern. In the case of the above mentioned subcatchment the computations show that, for a ponding depth of one meter, a detention area of approximately 550 square meters would be required. However, a detention storage for a drainage area would not necessarily be effective in enhancing infiltration unless it is unlined and the underlying soils are sufficiently permeable.

At Karanawanwatta industrial estate at the time of inspection to investigate the need for environmentally sustainable infrastructure in October 1996, most of the road culverts had already been constructed and the road bitumen surfacing had been completed. Industry allotments had already been laid out on the blocking-out plan which was made available for the industrialists to select industrial sites. Since the culvert invert and the road surface elevations were already fixed, it was not possible to provide a meter depth of detention; thus more surface area will be required to achieve the same volume of detention arising under the condition of environmental mitigation. Therefore, inclusion of a single detention storage pond for each subcatchment at the exit point of each catchment required an impossible task of re-blocking out of the property.

Considering these constraints, a simple system of cascade detention ponds was incorporated to overcome the restrictions on obtaining a single detention pond. To ensure spatial contributions to the subsurface flows, the environmentally sustainable infrastructure proposals included unlined detention ponds. Since percolation tests revealed that within most parts of the estate soils had excellent permeability, the task of incorporating a distributed pond system was made easy. Based on the computed volume requirement per unit area, an unlined pit with a depth of one meter was included at each allotment for the purpose of retention and detention of rainwater. Computations involved a modelling exercise incorporating the water balance at the pit environment considering infiltration inflow and storage limitations. Downstream wall of these pits was proposed to be with loosely packed rubble to retard the passage of surface runoff (**Figure 4**). Selection of the pond system was based on current practices (NCHRP 174-1981, CIRIA 156-1996) while considering the need for simple, low-cost strategies to convince the authorities to incorporate the mitigatory measures in the conventional development programme. In order to assist the developers to easily construct these infiltration/detention ponds, recommended locations were also demarcated on the layout map for each allotment (Figure 3). **Table 2** shows the recommended detention/infiltration pond sizes for allotments. Developers of the industrial estate site were requested to maintain a grass belt of at least one meter width on the upstream edges with the intent of reducing debris and silt entering the pit. Periodical desilting to maintain the designed depth was recommended to ensure proper functioning of this scheme.

6.0 Road Drainage

Two earthen drains of 450mm x 450mm in section on either side of the roads were included in the road construction activity. The earth drainage canal network shown in Figure 3 is designed to lead stormwater to culvert locations. During field visits it was observed that a few already-constructed culverts were located away from the vally; thus requiring landscaping to divert drainage water through the

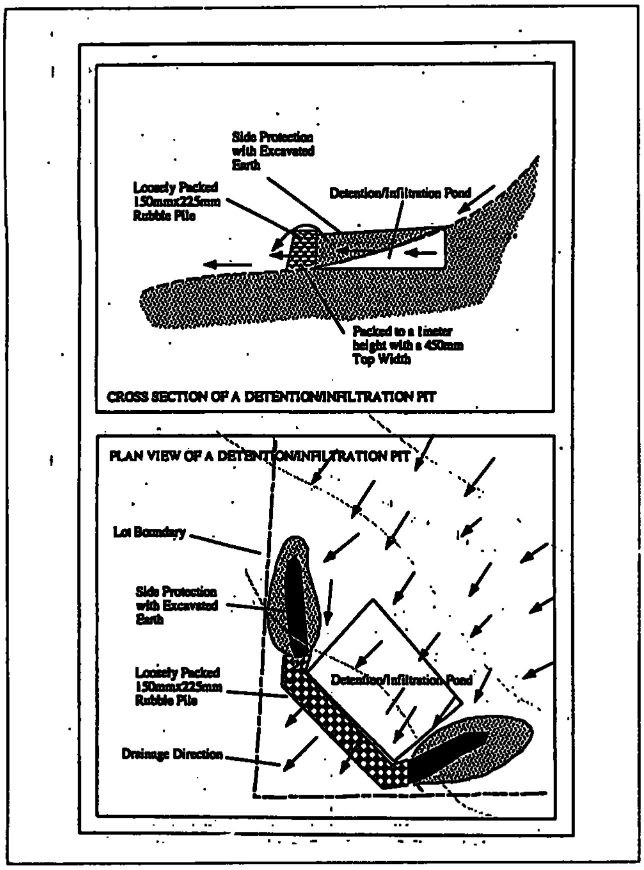

Figure 4: Typical Allotment Based Detention/Infiltration Pond

structure. Based on the drainage patterns, and to ensure disposal of stormwater without interfering with the internal road network, a few additional culverts were recommended for construction. Though the pre-existing culverts and road surface levels were constraints to providing significant detention at the culvert locations, a system of detention and infiltration pond arrangement was adopted within the limited space available **(Figure 5).** These detention ponds incorporated at culvert locations are meant to trap stormwater that would bypass the spatially-distributed pond network. They also retard the runoff water from road surfaces reaching the culvert locations via the road side drains. These detention ponds are also to be kept unlined to enhance the water infiltration into sub surface layers. Turfing near the detention ponds and the recommended rubble packed belt shown in **Figure 5** are intended to reduce silt and debris entering the pond. These ponds also require periodic desilting and maintainance to ensure satisfactory functioning.

7.0 Drainage Across Boundaries

Blocking-out of the area pertaining to the industrial estate should provide for adequate draining of surface water across properties. It is important to ensure that the natural drainage paths be maintained as far as possible during the construction of boundary walls to ensure that stormwater drainage does not deviate substantially from pre-construction stage. Drainage pattern of this industrial estate clearly indicates that

Table 2
Recommended Detention/Retention Ponds for Land Allotments

Size of Allotment (ha)	Typical Values for Detention/Retention Pond	
	Length (m) & Width (m)	Depth (m)
0.10	2.65 X 2.65	1.0
0.15	3.20 X 3.20	1.0
0.20	3.75 X 3.75	1.0
0.25	4.20 X 4.20	1.0
0.30	4.60 X 4.60	1.0
0.35	4.95 X 4.95	1.0
0.40	5.30 X 5.30	1.0
0.45	5.60 X 5.60	1.0
0.50	5.90 X 5.90	1.0

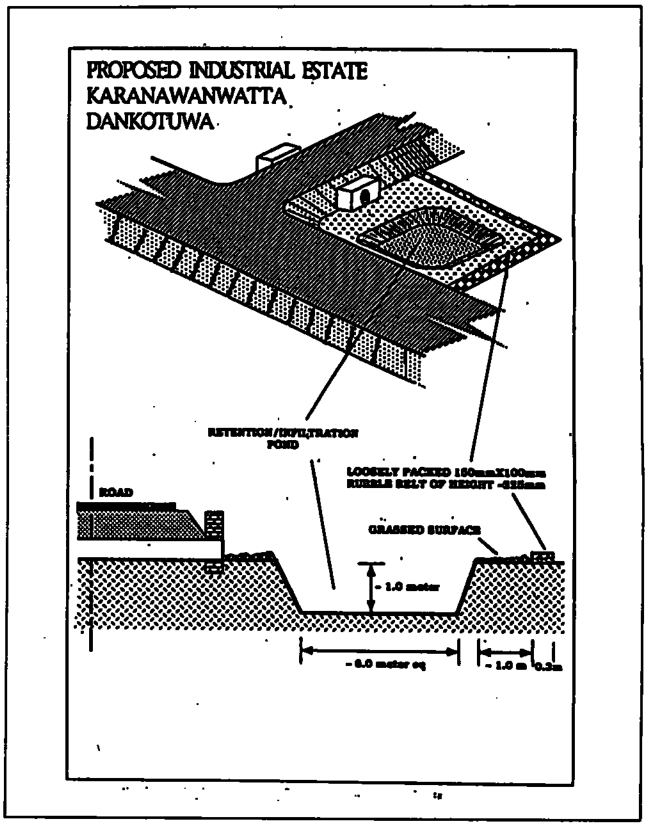

Figure 5: Typical Retention/infiltration Facility Near Culverts

paths of surface flow across the lot boundaries and the sloping terrain of the estate would lead to prominent cross-drainage flows. Hence to ensure natural cross-drainage within the estate it was recommended to avoid boundary walls that create obstruction to surface flow. As the area becomes developed resulting in increased runoff coefficients, cross-surface flows become more significant during heavy showers, causing inconvenience to downstream occupants.

Since all properties within the industrial estate are enclosed by a main security fence right round the perimeter, isolating the estate from surrounding habitats, it was recommended not to encourage building of boundary walls around each individual property. Instead, wire fences could be put up with individual footings for fence posts, thus permitting surface water to flow without introducing new constraints.

As a measure to ensure the sustainability of cross-drainage provisions, recommendations were made to leave strip of 3 meters at each common boundary with a common earth drain at the center where necessary, with two rows of trees on either side of the drains. Common strip is recommended to be the property of the Industrial Estate Management Unit and not of the individual property holders. This strip is to facilitate retarding of cross-drainage surface runoff reaching downstream, and would also provide the purpose of a wind barrier across the Industrial Estate and a green, shady environment. The trees to be planted in the common strip required to be ecologically sustainable and should serve the intended purposes but the remaining surface of this strip should not be void of vegetation. Typical cross section of the recommended common strip and the common strip locations are shown in **Figure 6.** When the land extent of a single owner is a combination of more than one demarcated allotment, the management was recommended to ensure the establishment of proportionate green strips within the premises.

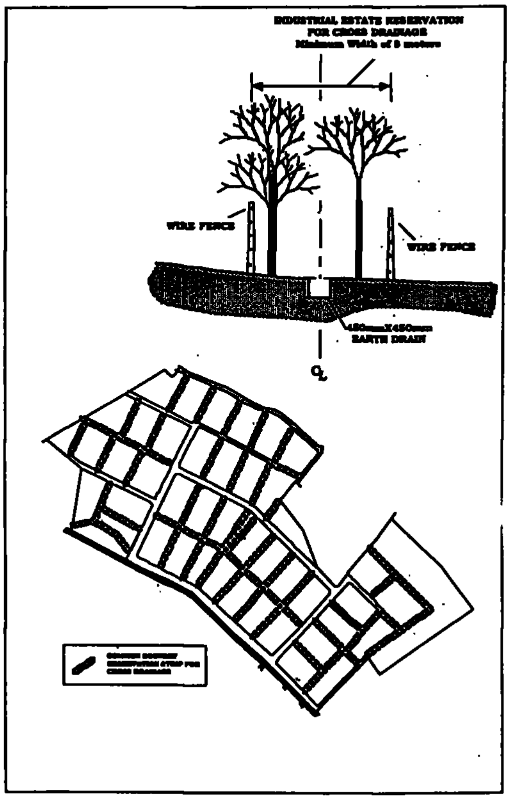

Figure 6: Cross Drainage Reservation Layout

8.0 Implementation

Incorporation of environmentally sustainable infrastructure calls for a significant deviation from customary development practices in the country. Developers do not usually incorporate such stormwater impact mitigation structures into their plans, since omitting such elements is not perceived as causing any adverse impact on themselves, especially when no use is made of the rainwater received at the property targeted for development. This attitude is encouraged when the developers are assisted with pipe-borne water, thus discouraging any interest in preserving surfacewater or groundwater for consumption. Even in the cases where groundwater is tapped for consumption, developers show little interest in replenishing the aquifers since such action would require additional capital expenditures that would yield results only in the years to come. Majority of developers tend to pave their industrial compounds and resort to lined drainage networks to ensure fast disposal of stormwater as a means of ensuring drainage.

In the case of Karanawanwatta industrial estate, the Ministry of Industries is operating under a cabinet directive to execute the development of the basic infrastructure such as roads, electricity, water supply etc., for the estate to assist the industrialists in setting up individual industries. Additional space requirement for detention/infiltration pits and common cross-drainage reservations was a major concern since these measures had not been accounted for in the initial plans. There was concern that excessive space reduction from the original plan might lead to insufficient space for industries since the proposed estate is only 23.5 hectares in extent; thus the site might not fulfill the concept of an industrial estate as envisaged by the government. Any facilities added beyond the reservations already allocated in the blocking-out plan could mean surveying of the site and mapping to carry out reblocking-out to suit desired modifications. Land reductions may not be favoured by the industrialists since land is a constraint even at present. Any fresh blocking-out work could require additional time, thus causing delays in implementation activities. These factors were taken into consideration in selecting the size of stormwater retention facilities, location, and type of structure.

Structures for the mitigation of impacts had to be very simple, easy to understand, and easy to construct because there was a strong need to convince the developers to undertake protecting the environment at a minimal cost and with the least deviation from time schedules. This was a key factor since developers in the past were not incorparating such environmental concerns into property development.

Detention and infiltration pond system involved no masonry construction. Only simple earth excavation and loose rubble packing were the techniques involved, thus relieving a developer of the need to engage specialist contractors, or consultants. The proposals proved to be simple to understand by non-technical persons and did not consume huge sums of money. Cross-drainage reservations were designed to include simple earth drains with tree planting to suit the purpose. The road drainage network and detention/retention facility system proposed for culvert locations were accepted to be incorporated into the initial infrastructure development programme of the Ministry of Industries. Proposals were submitted to the Ministry of Industries as Management recommendations for Industrial Estate Development.

9.0 Summary

Unplanned development activities lead to excessive erosion, siltation and problems in drainage across land boundaries. Such actions also lead to deterioration of groundwater resources seriously effecting the soil moisture conditions. Mitigating such environmental consequences could be carried out by systematic analysis of water balance and incorporating suitable engineering structures. It is evident that simple engineering techniques could mitigate the consequences from the development activities. Presentation of possible simple applications to the developers need to convince the easiness of the incorporation of such into the development activities. Simple models using Water Balance Studies can be easily incorporated to design suitable stormwater management structures. Recommended detention/retention storages were incorporated as spatially distributed system thus relieving the burden on the central management.

The environment management proposals incorporated in this work is easy to understand, easy to construct, low cost and do not require special skills for construction. The proposals considered the incorporation of such structures which giving due consideration to the space constraints of the industrial land owners.

10.0 Acknowledgments

The author is grateful to the NAREPP/IRG of the USAID for permission to publish the present work. Valuable discussions with the Ministry of Industry officials Mr. RVD Piyathilleka (Director), Mr. Asitha Seneviratna (Asst. Director) and Regional Director Mr. Harischandra, as well as NAREPP officials, Mr. Edward Scott, Mr. Ari Hewage, Dr. Robert Smythe and Mr. Sanath Ranawana are highly appreciated.

11.0 References

Chow et. Al 1988	Chow Ven Te, Maidment D.R, and Mays.LW - Applied Hydrology, Mcgraw Hill Book Company PP 419, 498, 522, 1988
CIRIA 156-1996	Construction Industry Research and Information Association, Report 156-Infiltration Drainage-Manual of Good Practice, CIRIA, London, 1996
Dept of Irrig 1980-1	Department of Irrigation Technical Notes -No 2, Design of Embankments for village tanks and medium reservoirs 1980
Dept of Irrig 1980-2	Department of Irrigation Technical Notes -No 2, Annex 5, 1980
Dharmasena &	Premasiri 1990 Dharmasena G.T., Premasiri S., M., Rainfall Intensity Studies for Sri Lanka, ENGINEER, Journal of the Institution of Engineers, Sri Lanka, December 1990
NAREPP 1995	Initial Environmental Examination of the Proposed Industrial Estate at Karanawanwatta (Dankotuwa), Natural Resources and Environmental Policy Project (NAREPP) of USAID, 1995 NCHRP 174-1981

National Cooperative Highway Research Program Synthesis of Highway Practice, Stormwater Management for Transportation Facilities-174, Transportation Research Board, National Research Council, Washington DC, 1993

Schwab et al 1981	Glenn O. Schwab, Richard K. Frevert, Talcott W. Edminster, Kenneth K.Barnes - Soil and Water Conservation Engineering, John Wiley & Sons, Appendix A, 1981