No.

Siem Reap Province and APSARA Authority, the Royal Government of Cambodia
Japan International Cooperation Agency

The Study on Integrated Master Plan for Sustainable Development of Siem Reap / Angkor Town in the Kingdom of Cambodia

FINAL REPORT

VOLUME III SECTOR REPORT PART 2

March 2006

International Development Center of Japan
Nippon Koei Co., Ltd.
Kokusai Kogyo Co., Ltd.

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Currency Equivalents
(Official Exchange Rate in 2004)
US$ 1 = 4,016Riel

Unless Specifically Noted

Preface

In response to a request from the Royal Government of Cambodia, the Government of Japan decided to conduct “The Study on Integrated Master Plan for Sustainable Development of Siem Reap/Angkor Town in the Kingdom of Cambodia” and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent a study team headed by Dr. Jinichiro Yabuta of International Development Center of Japan to Cambodia from November 2004 to March 2006.

The team held discussions with the officials concerned in the Royal Government of Cambodia, and conducted field surveys in the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to sustainable development of Siem Reap/ Angkor Town and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials of the Government and those concerned in Cambodia for the close cooperation they have extended to the study.

March 2006

Takashi Kaneko
Vice President
Japan International Cooperation Agency

March 2006

Mr. Takashi Kaneko
Vice President
Japan International Cooperation Agency
Tokyo, Japan

Dear Mr. Kaneko,

Letter of Transmittal

We are pleased to submit the final report of the Study on Integrated Master Plan for Sustainable Development of Siem Reap/Angkor Town in the Kingdom of Cambodia. The final report is comprised of three volumes, namely, Volume 1: Executive Summary; Volume 2: Main Report; and Volume 3: Sector Report.

Since the historic remains in Siem Reap/Angkor Town are not only the world's cultural heritage but also the symbol of Cambodia in terms of nation's identity, as well as her major source of foreign exchange, an attempt at transforming the Town into a model city with highly sustainable development is meaningful. However, the Town should not be sustainable only in itself by merely attracting tourists to a cluster of historic remains, but instead, to serve as a model city that represents an ideal image of sustainable development in the 21st Century. Repetitive adjustments and improvements will be necessary in the process, but insights into Angkorian wisdom and efforts toward creating environment-friendly atmosphere may help the Town achieve its goal of transforming into a model city with highly sustainable development.

To this end, the currently booming tourism should be transformed to more balanced and quality oriented with a smaller loads to the natural environment. It is highly advised that the Government of Cambodia seriously tackle with urban/environmental management, including water- and land-use control, which is considered indispensable in realizing a model city with truly sustainable development.

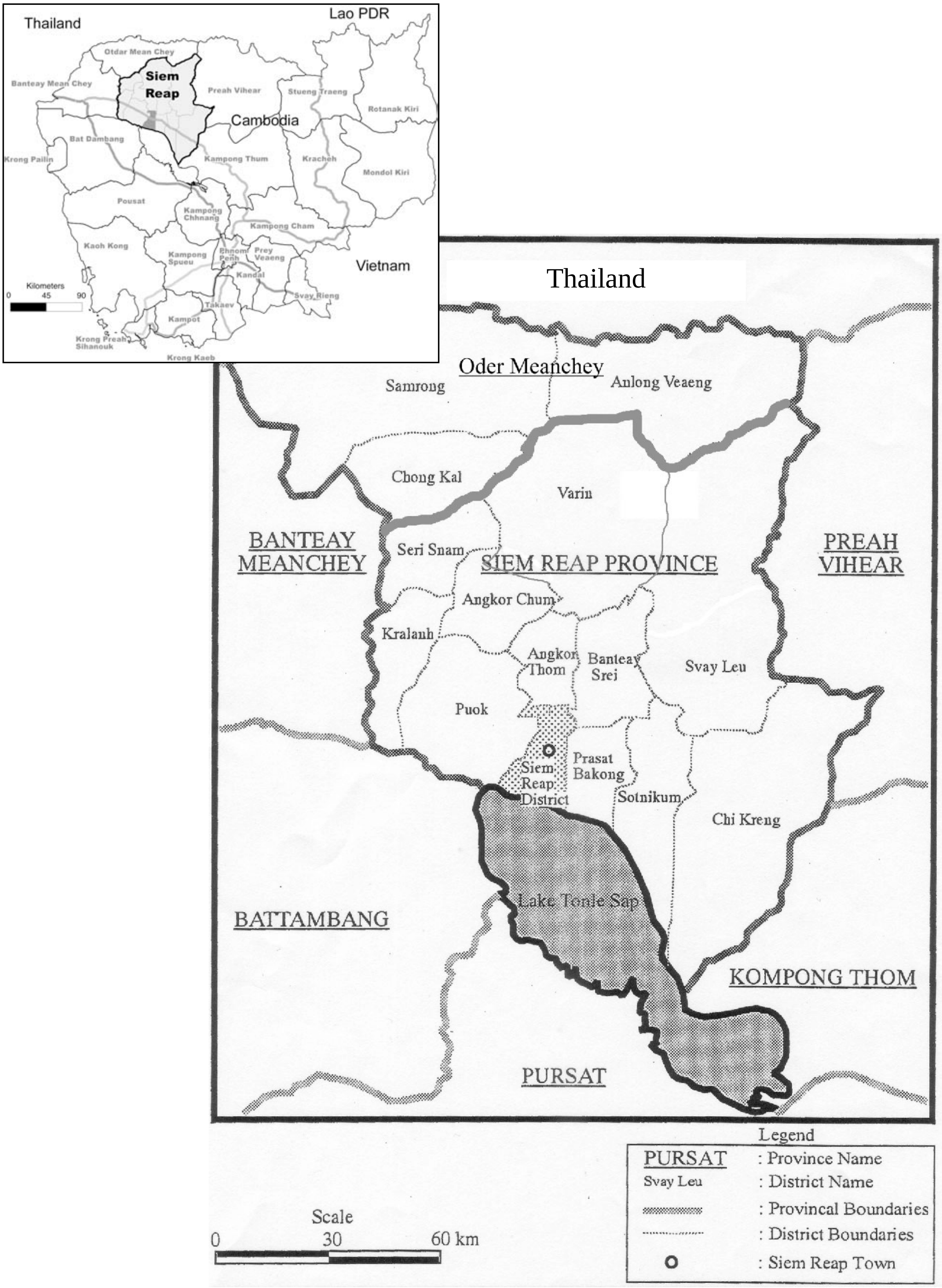
The long-term master plan suggested in the final report should not be regarded as fixed and definite. Therefore, revisions and adjustments are welcomed in accordance with the changing circumstances, whereas the proposed priority projects should fully and constantly be reviewed for timely preparation and implementation. On the other hand, the provincial government is advised to strengthen its capacity to monitor, plan and maintain projects, with the support from specialized national agencies, such as APSARA and related ministries.

We wish to take this opportunity to express our sincere gratitude to your Agency, Siem Reap Province, APSARA Authority, Council of the Development of Cambodia and other distinguished authorities of the Royal Government of Cambodia for their invaluable cooperation and assistance to the Study.

We do hope that this report will contribute to the sustainable development of Siem Reap/Angkor Town.

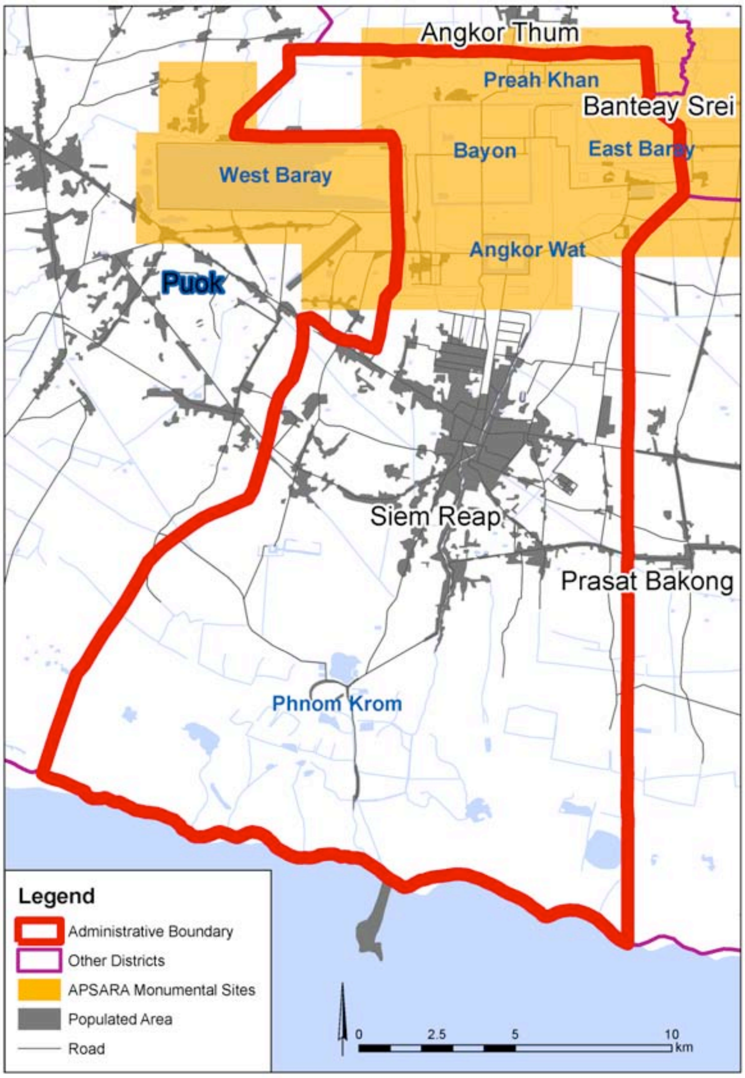
Very Truly Yours,

Jinichiro Yabuta
Leader
JICA Study Team and
Study Consortium by
International Development Center of Japan,
Nippon Koei Co., Ltd. and
Kokusai Kogyo Co., Ltd.

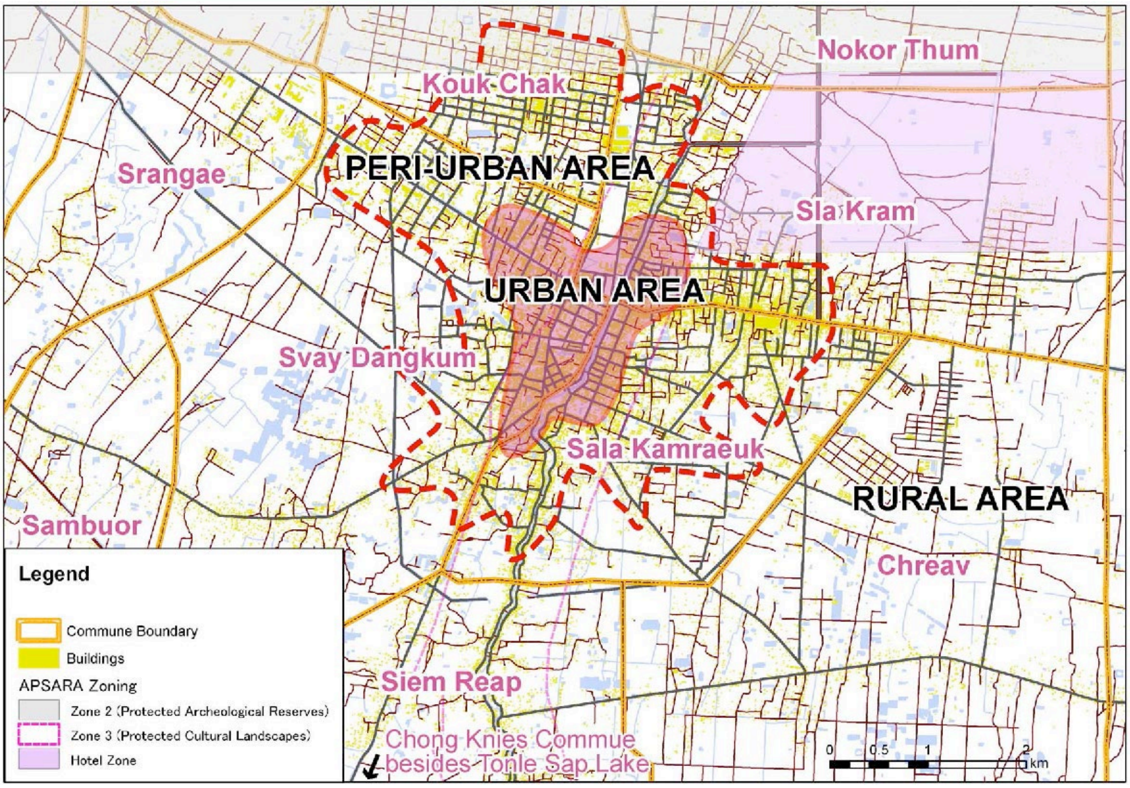


Location of Siem Reap Province and Siem Reap District

Siem Reap District



Central Area of
Siem Reap District



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Abbreviation List

AA	:	Artisan D'Angkor
ACE	:	Australian Center for Education
ACP	:	Asbestos Cement Pipe
ADB	:	Asian Development Bank
AFD	:	Agency France Development
AIDS	:	Acquired Immune Deficiency Syndrome
APPC	:	Angkor Product Promotion Center
ASEAN	:	Association of South East Asian Nations
AUPPT	:	Asia Urbs Project Provincial Towns
BHN	:	Basic Human Needs
BOD	:	Biological Oxygen Demand
BOT	:	Build, Operate and Transfer
CAMS	:	Cambodian Airport Management System
CAU	:	Contract Administration Unit
CC	:	Commune Council
CD	:	Compact Disk
CDC	:	Council for Development of Cambodia
CEFP	:	Chanties-Ecoles de Formation Professionelle
CEO	:	Chief Executive Officer
COD	:	Chemical Oxygen Demand
CS	:	Conventional Sewerage
CTMPB	:	Cambodian Tourism Marketing and Promotion Board
DC	:	District Council
DEF	:	Department of Economy and Finance
DIME	:	Department of Industry, Mines and Energy
DLMUPC	:	Department of Land Management, Urban Planning and Construction
DOE	:	Department of Environment
DOT	:	Department of Tourism
DOWRAM	:	Department of Water Resources and Meteorology
DPWT	:	Department of Public Works and Transport
EAC	:	Electricity Authority of Cambodia
ECOTEL	:	Eco-label for hotel by the Danish Green Key Organization
EdC	:	Electricite du Cambodge
EDS	:	Effluent Drainage System
EGAT	:	Electricity Generating Authority of Thailand
EGCO	:	Electricity Generating Public Company Limited
EIA	:	Environment Impact Assessment
EIC	:	Economic Institute of Cambodia
EM	:	Environment Management
EMS	:	Environmental Management System
EU	:	European Union
FU	:	Financial Unit
GDP	:	Gross Domestic Products

GIS	:	Geographical Information System
GMS	:	Greater Mekong Sub-region
GPN	:	Green Purchase Network
GRDP	:	Gross Regional Domestic Product
HCC	:	Hygiene Care Cambodia
HIV	:	Human Immunodeficiency Virus
ICAO	:	International Civil Aviation Organization
IEIA	:	Initial Environmental Impact Assessment
IFAD	:	International Fund for Agricultural Development
IKTT	:	Institute of Khmer Traditional Textile
IMF	:	International Monetary Fund
IPP	:	Independent Power Producer
ISO	:	International Standard Organization
ISRI	:	International Standard Research Institute Inc.
IT	:	Information Technology
IWRM	:	Integrated Water Resources Management
JICA	:	Japan International Cooperation Agency
JIS	:	Japanese Industrial Standard
JOCV	:	Japan Overseas Cooperation Volunteer
JPA	:	Job Placement Agency
JQAI	:	Quality Assurance Institute Inc.
JQR	:	Japan Quality Assurance Organization
JST	:	JICA Study Team
KAF	:	Konrad Andenauer Foundation
KOICA	:	Korea International Cooperation Agency
kWh	:	Kilowatt x Hour
Lao PDR	:	Lao People's Democratic Republic
LAU	:	Local Administration Unit
LBAT	:	Labor-Based Appropriate Technology
MCS	:	Modified Conventional Sewerage
MEDS	:	Modified Effluent Drainage Servicing
MEF	:	Ministry of Economy and Finance
MGC	:	Mekong Ganga Cooperation
MICC	:	Multiple Investment Cooperation Company
MICE	:	Meeting, Incentive, Convention and Events
MIME	:	Ministry of Industry, Mines and Energy
MLMUPC	:	Ministry of Land Management, Urban Planning and Construction
MOE	:	Ministry of Environment
MOT	:	Ministry of Tourism
MOU	:	Memorandum of Understandings
MOWRAM	:	Ministry of Water Resources and Meteorology
MPTW	:	Ministry of Public Works and Transport
MRD	:	Ministry of Rural Development
MSL	:	Mean Sea Level
NAS	:	Sodium-Sulfur
NGOs	:	Non-governmental Organizations

Nox	:	Nitrogen Oxydes
NPRS	:	National Poverty Deduction Strategy
NR	:	National Route
NR6	:	National Route No 6
NRDP	:	Northwest Regional Development Project
NRW	:	Non Revenue Water
OWO	:	One Window Office
OWSO	:	One Window Service Office
PADAP	:	Program for Suburban Agricultural Development
PAP	:	Priority Action Program
PAPs	:	Project Affected Persons
PCU	:	Passenger Car Unit
PDCA	:	Plan-Do-Check-Action
PIF	:	Provincial Investment Fund
PIU	:	Project Implementation Unit
PLG	:	Partnership for Local Governance
PM	:	Particulate Matters
PMU	:	Project Management Unit
PPA	:	Power Purchase Agreement
PPP	:	Public and Private Partnership
PRDC	:	Provincial Rural Development Committee
PS	:	Pump Station
PSD	:	Private Sector Participation
PUR	:	Plan d'Urbanisme de Reference
PUSC	:	Plan d'Utilisation des Sols et de la Construction (Land Use and Construction Plan)
PVC	:	Polyvinyl Chloride Pipe
RGC	:	Royal Government of Cambodia
ROW	:	Right-of-Way
SANDEC	:	Sanitation in Developing Countries
SARS	:	Severe Acute Respiratory Syndrome
SCA	:	Societė Concessionaire de l'Aeroport
SEAMEO	:	South East Asian Minister of Education Organization
SEDP II	:	Socio-Economic Development Plan II
SEDP	:	Socio-Economic Development Plan
SEILA	:	Social Economic Improvement for Local Area
SME	:	Small and Medium Enterprise
SOx	:	Sulfur Oxides
SPAFA	:	SEAMEO Regional Center for Archeological and Fine Arts
SPEU	:	Sewerage and Public Electricity Unit
SRAT	:	Siem Reap Angkor Town
SRTMPB	:	Siem Reap Tourism Marketing and Promotion Board
SRTO	:	Siem Reap To└ urism Office
SS	:	Suspended Solid
SSCA	:	State Secretariat of Civil Aviation
SWM	:	Solid Waste Management

TCD	:	Town Center Drain
TG	:	(II-6-12)
T-N	:	Total Nitrogen
T-P	:	Total Phosphorous
TPC	:	Table of Parameters and Constructions
TSP	:	Total Suspended Particulate
TSS	:	Transport Sector Strategy Study
TSU	:	Technical Support Unit
TTA	:	Tourists Transport Association
UFW	:	Unaccounted for Water
UK	:	United Kingdom
UNDP	:	United Nations Development Programs
UNESCO	:	United Nations Education, Scientific and Cultural Organization
UNHCR	:	United Nations High Commission for Refugees
UNICEF	:	United Nations Children's Fund
USD	:	United States Dollar
VAT	:	Value Added Tax
VDC	:	Village Development Committee
WAPCOS	:	Water and Power Consultancy Services
WB	:	World Bank
WFP	:	World Food Program
WHO	:	World Health Organization
WMF	:	World Monument Fund
WSP	:	Waste Stabilization Pond
WSPs	:	Water Stabilization Ponds
WW	:	Wastewater
ZEMP	:	Zoning and Environment Management Plan

Chapter 9 Drainage and Sewerage

9.1 Present Situation and Issues

9.1.1 Overview

The present situation regarding sewerage and sanitation in Siem Reap can be summarized as follows:

Drainage	• Open drains have insufficient capacity for stormwater • Frequent flooding in the central commercial and tourist accommodation area • Open drains filled with garbage
Sanitation/Health	• Inundation of streets and properties by stormwater combined with sanitary wastewater during heavy rainfall • Health and aesthetic problems caused by inadequate sanitation in high density and low income areas • Effluent from septic tanks and wastewater discharged directly to drains, creating disease vectors
Environmental	• Increasing pollution levels in Siem Reap River, drains and irrigation canals • Drainage ditches and groundwater increasingly contaminated by wastewater and infiltration of runoff

There is no sewer system for the evacuation of domestic wastewater and consequently no sewage treatment facility. On-site sanitation using septic tanks is prevailing. Nevertheless it is important to state that the drainage system, conceived for the removal of stormwater, de-facto acts as a combined sewer system also removing wastewater.

Domestic wastewater from toilets is pretreated in septic tanks but grey water (kitchen/wash water) and septic tank effluent cannot infiltrate due to low soil permeability. Most wastewater ends up in the open drainage system.

9.1.2 Sewerage and Sanitation Systems

Sewerage is defined as the collection of wastewater in a network of pipes and conveyance to a treatment plant.

At present, there is no sewerage system. The majority of households, hotels and guest houses discharge sanitary wastewater (from toilets) into septic tanks or interceptor vaults. Wastewater from kitchen or bathing use is discharged without treatment to open drains or into storm sewers where they exist.

Informal settlements to the North and South along Siem Reap River do not have adequate sanitation. In these low income areas open defecation or over hang latrine prevails. This is a significant source of faecal coliform contamination in the Siem River since there are large informal settlements along the river banks to the North and South of city center.

A survey by the Study Team found that the septic tanks and interceptor vaults are not functioning well in most cases. There is no construction code enforced to specify the required design. Another major reason is lack of maintenance and cleaning. There is no supervision for de-sludging activities. It is reported that there are some private operators who carry out de-sludging. The biggest of them is operating with a 4000 litre capacity vacuum truck and charges 40$ for each cleaning. The sludge is disposed overland at a 5 ha low land owned by the operator. Most hotels maintain their septic tanks in relatively better condition and some of the large hotels even have advanced treatment units including activated sludge or anaerobic process followed by filtration. This is because hotels are required to equip with treatment facilities by the laws and it is supervised by the Provincial Department of Land Management, Urban Planning and Construction.

The majority of present sewers are financed by the nearby residents and built either by themselves or by commune authorities. However, the construction of sewers is neither endorsed by DPWT nor supervised. As a result, faulty construction without proper levelling and gradient is common. Thus, the system is not functioning properly and in the rainy season leads to localized flooding of sewage. DPWT owns only 4 km of stormwater sewers, constructed in 1950s covering only town center. Most of these sewers will likely need to be replaced since they were poorly constructed to begin with and will likely not be appropriately graded or configured for the proposed new system.

9.1.3 Drainage Systems

In this study drainage is defined as the removal of stormwater runoff. Because there is no separate sanitary sewerage system, drainage also includes wastewater from domestic use as well as restaurants, hotels and institutional buildings. In many cases effluent from septic tanks is discharged to open drains and storm sewers.

(1) Drainage Patterns

Siem Reap is located in a very flat and low-lying area close to Tonle Sap Lake. The Siem Reap River flows through the city dividing it into East and West drainage areas. The river has a natural gradient of 1/1000 from North to South towards Tonle Sap Lake but the topography in the urban area is flatter and dotted with localized low-lying areas.

The water level in Tonle Sap fluctuates seasonally reaching its highest level near the end of the rainy season in September. The area below 10m MSL is usually flooded by the lake. The maximum elevation of the water surface in Tonle Sap lake is measured daily by the Mekong River Commission at Kampong Luong. The probability of high and low water levels in Tonle Sap (PLANCENTER, February 2004) is as follows:

Highest recorded high water level:	11.09m above MSL (mean sea level)
50 year recurrence	10.77m
20 year recurrence	10.65m
10 year recurrence	10.50m

The topographic contours and the direction of flow in drains indicate that most of the stormwater generated in the urban area flows away from the Siem Reap River therefore it can be deduced that pollution in the River is mainly from informal settlements along the river banks in the upstream reaches north of NR6.

A number of agricultural irrigation canals which date back to ancient Angkor civilizations still crisscross the study area (schematic Figure III.9.1). Many of these are in a state of disuse but others still function and carry water to agricultural areas located to the south west and south east of the city. Some of the canals are fed from the Western Barray and others are fed from Siem Reap River. Therefore the network of canals and drains always has a base flow even in dry weather which reduces the capacity for drainage of stormwater.

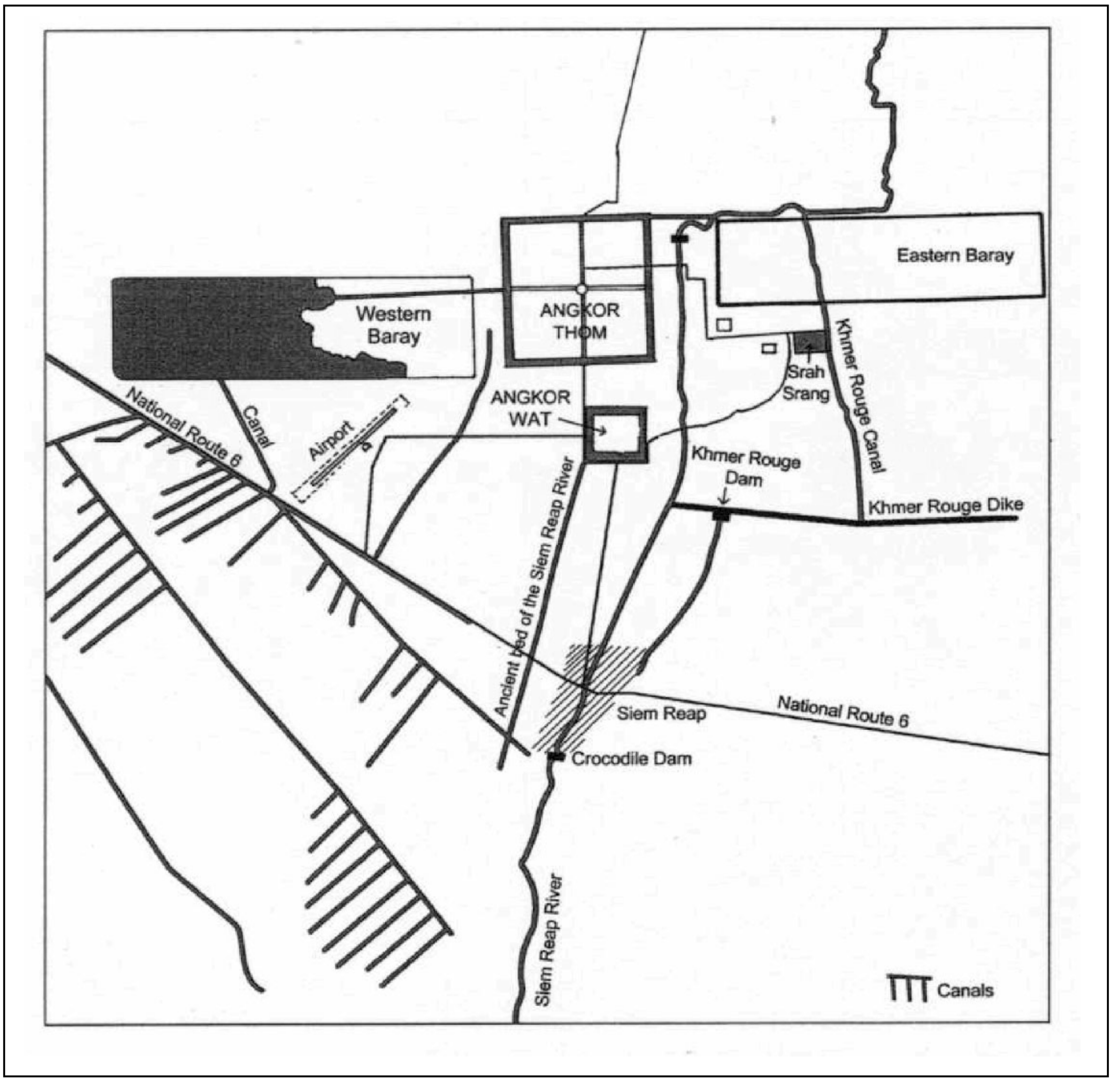

Figure III.9.1 Angkorian Canals and Waterways

(2) The Siem Reap River

Recent studies carried out by AFD indicate that the Siem Reap River has a number of hydraulic and water quality problems:

- Erosion upstream of the city where it crosses the Angkor site
- Insufficient capacity for peak flows during the rainy season
- Poor water quality defined by high levels of faecal contamination

Progressive erosion upstream near the Angkor site has led to significant sedimentation of the channel throughout the city and especially just upstream of the crocodile weir. The purpose of the weir, located just downstream of the city, is to divert water into irrigation canals on either side of the river. It consists of a permanent structure with three adjustable sluice gates and two permanent overflow structures.

During the rainy season the river carries significant flow, somewhere between 124m3/s and 143m3/s (estimated by consultants BCEOM for peak flows in September 1994). The recent AFD study has raised concerns that sedimentation could eventually cause the stream to overflow its banks and flood the city during peak flows. The potential for flooding is made worse by the on-going reduction in hydraulic capacity caused by informal settlements along the river banks as these fill in the river to build houses.

The river could be dredged to restore hydraulic capacity but this would only be a short term solution. Erosion protection in the upstream portions and along the river banks will be required for a more permanent solution.

The recent influx of construction and hotel workers has seen the growth of several informal settlements along the river banks:

- A number of settlements between the park entrance and the city
- Downstream of the old market up to the crocodile weir
- Downstream of the crocodile weir, considerable infilling of the river bed and a large number of houses overhanging the river.

These settlements are within the 500m protection zone on each side of the river however the authorities are reluctant or powerless to do anything about it. These settlements reduce the hydraulic capacity of the River and have become a significant source of water pollution (fecal contamination) as indicated by the water quality measurements taken by JICA study.

During the dry season flow in the river is very low leading to eutrophication and degradation of water quality. There is a need to maintain a minimum base flow to improve water quality and aesthetics however a balance must be achieved to satisfy other needs such as protection of the Angkor monuments and water for irrigation.

(3) Urban Drainage and the Environment

Heavy storm events can cause flooding. The effects of flooding can be severe. Water levels in drain and the Siem Reap River rise considerably and the flow of water can erode soils and embankments. Sediments which have been deposited in quiescent stretches of a stream can be re-suspended and transported further downstream. In urban areas the water picks up litter and solid wastes in its path as well as other diffuse pollution sources, and spread these in the downstream flooded areas. Aquatic environments like Tonle Sap and water-fowl habitats can be destroyed, and these may take some time to recover. The amenity value of the river is therefore degraded. Engineered structures, such as culvert and bridges, can be choked with wastes and debris, causing more wide-spread flooded areas.

(4) Urban Drainage and Public Health

In poorly drained areas, urban runoff mixes with sewage from overflowing latrines and sewers, causing pollution and a wide range of problems associated with waterborne diseases. Flooded septic tanks and leach pits provide breeding sites for mosquitoes, and faecally contaminated wet soils provide ideal conditions for the spread of intestinal worm infections. Infiltration of polluted water into low-pressure water-distribution systems contaminates drinking water supplies causing outbreaks of diarrhea and other gastro-intestinal illnesses.

(5) Operational Performance and Maintenance of Drains

The drainage system in the city is characterized by close-to-zero gradients because of the flat topography, which makes it very vulnerable to blocking caused by settled solids and dumped rubbish. Many problems associated with the operation of stormwater drainage systems are linked to poor solid waste management. Municipal agencies responsible for solid waste management lack sufficient resources and equipment for drain cleaning. There is often poor communication and co-ordination between the different urban authorities responsible for operating and maintaining the various components of the drainage network.

Poor design and poor construction practices also contribute to poor drainage and flooding. Typical problems include:

- Drains that have reverse grades and sumps
- Insufficient number of culverts or inadequate culvert sizes at road crossings
- Insufficient number of curb inlets on paved streets
- Many crossing drains where grades are not properly matched e.g. Upstream lower than downstream.

(6) Specific Problem Areas

1) North of NR6

The chaotic nature of urban development along national route 6 (NR6) has resulted in a number of significant hydraulic bottlenecks. Historical drains and irrigation canals flow perpendicular to this urban axis therefore stormwater runoff generated to the north must cross NR6. Ditches have been constructed along NR6 to convey stormwater however flow has been obstructed by the construction of hotels and culverts crossing the road are insufficient in numbers and in capacity. As a result NR6 has in effect become a dike and large areas north of NR6 suffer chronic flooding that lasts for extended periods during the rainy season.

2) City Center - South West of NR6

The central core of the city has a network of combined sewer pipes that carries stormwater and wastewater to the Town Center Drain and further west to a small storage lagoon. The large area north of NR6 between the hospital and the river is also served by stormwater pipes and discharged to the TCD. The TCD is an open drain that discharges stormwater combined with wastewater to the irrigation canal along road no. 52.

Residential housing and commercial developments in this area exacerbate urban drainage problems by increasing the impermeable areas that produce urban runoff.

The town center drain is not wide or deep enough to accommodate all the runoff generated by such a large area therefore additional drains will be required to accommodate future development. Drainage of runoff is restricted by downstream flow constrictions such as illegal construction in the floodplain but there is often little control over new developments.

The piped stormwater collection system is in very poor condition. Many of the pipes are poorly installed, under sized and obstructed by the many new construction projects in the city.

Main flood prone areas are shown in Figure 1 (Appendix). The worst flooding occurs along the TCD and sections of Shivata Rd from central market to NR6. A low point along this section occurs at Samdach Tep Vong St. and this is where most of the water collects.

Flooding along Shivata Rd

The old market area is usually not too seriously affected by flooding probably because many of the stormwater drains have been redirected by local shop owners to the Siem Reap River. However the street surfaces are in poor condition and many large puddles form making it difficult for tourists to walk around.

Localized flooding occurs along many roads within the central core because road grading is poor and there are inadequate numbers of roadside gutters. As a result stormwater remains trapped and forms large pools in many localized low spots along the road. These pools eventually dissipate but they are a significant inconvenience to pedestrians and vehicles.

3) East District – South of NR6

Drainage comprises mainly open drains connected to irrigation canals along Cheavs Bridge Rd and Cheavs Commune Rd. In some sections the drains have been replaced by 1000mm ND concrete pipes. The system is in need of maintenance but appears to be functioning for the time being. The capacity of the canals and drains in downstream sections will be insufficient to accommodate the larger flows that will come as the areas become more developed. Additional capacity will also be required if APSARA proceeds with recommendations to convey stormwater from the special cultural/hotel zone towards a lagoon south of NR6.

9.1.4 Present Maintenance Organization

Drainage and sewerage in the Siem Reap is under the responsibility of Sewerage and Public Electricity Unit (SPEU), Department of Public Works and Transport (DPWT) of Siem Reap Province. DPWT is the line department of Ministry of Public Works and Transport, and works under Siem Reap Provincial Government. The DPWT in Siem Reap is headed by Director and has 4 deputy directors. The organization chart is shown in the figure below.

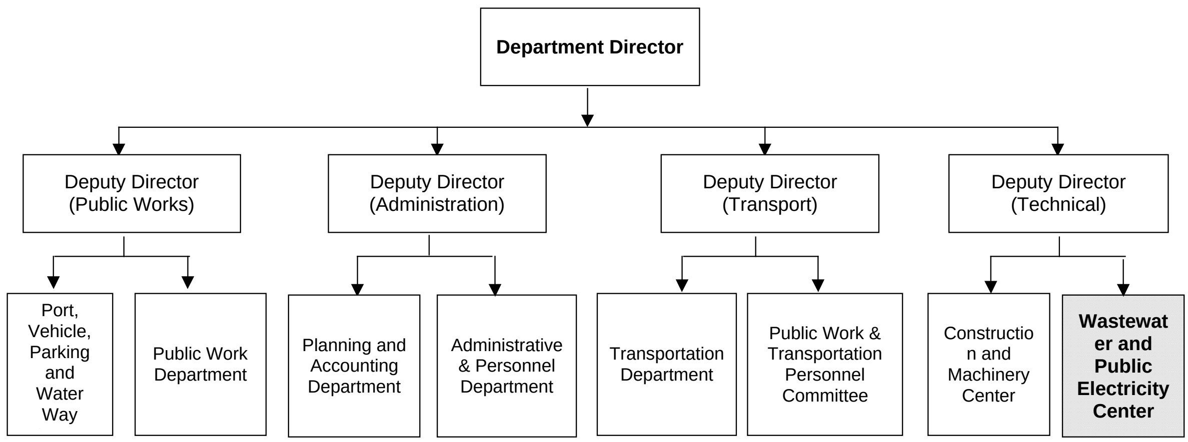

Figure III.9.2 Organization Chart of Provincial Department of Public Works and Transportation

The total number of staff in the SPEU is six; and comprises of one engineer, two technicians and three support staff. However, no one has training on sewerage and drainage. Data management is not systematically done, and they have no network map or inventory. They even have no equipment for cleaning the sewers.

9.1.5 Laws and Policies Related to Sanitation and Pollution Control

(1) Water Pollution Control

In April 1999, a Sub-Decree was enacted regarding water pollution control called "Sub-Decree on Water Pollution Control". The main purpose of this Sub-Decree is to regulate, prevent and reduce the water pollution of the public water areas so that the protection of human health and the conservation of bio-diversity are ensured. This law defines the public water areas, sources and types of pollution. It also states that an effluent discharge permit will be required for any type of disposal into public water bodies. Sewerage Treatment Plant comes into Category I, which means if the discharge is more than 10m3/d, it is subject to prior permission from the Ministry of Environment.

The effluent standard for discharging into public water areas is given in the Table III.9.1. From the table, it is seen that there are two sets of standards, one for protected public water areas such as Lake Tonle Sap and Siem Reap River and another for discharge to sewers. There are no standards regarding the discharge of treated effluent to agriculture.

Table III.9.1 Wastewater Effluent Discharge Standard

Nº	Parameters	Unit	Allowable limits for pollutant substance discharging to	
			Protected public water area	Public water area and sewer
1	Temperature	^0C	< 45	< 45
2	pH		6 – 9	5 - 9
3	BOD_5 (5 days at 200 C)	mg/l	< 30	< 80
4	COD	mg/l	< 50	< 100
5	Total Suspended Solids	mg/l	< 50	< 80
6	Total Dissolved Solids	mg/l	< 1000	< 2000
7	Grease and Oil	mg/l	< 5.0	< 15
8	Detergents	mg/l	< 5.0	< 15
9	Phenols	mg/l	< 0.1	< 1.2
10	Nitrate (NO_3)	mg/l	< 10	< 20
11	Chlorine (free)	mg/l	< 1.0	< 2.0
12	Chloride (ion)	mg/l	< 500	< 700
13	Sulphate (as SO_4)	mg/l	< 300	< 500
14	Sulphide (as Sulphur)	mg/l	< 0.2	< 1.0
15	Phosphate (PO_4)	mg/l	< 3.0	< 6.0
16	Cyanide (CN)	mg/l	< 0.2	< 1.5
17	Barium (Ba)	mg/l	< 4.0	< 7.0
18	Arsenic (As)	mg/l	< 0.10	< 1.0
19	Tin (Sn)	mg/l	< 2.0	< 8.0
20	Iron (Fe)	mg/l	< 1.0	< 20
21	Boron (B)	mg/l	< 1.0	< 5.0
22	Manganese (Mn)	mg/l	< 1.0	< 5.0
23	Cadmium (Cd)	mg/l	< 0.1	< 0.5
24	Chromium $(Cr)^{+3}$	mg/l	< 0.2	< 1.0
25	Chromium $(Cr)^{+6}$	mg/l	< 0.05	< 0.5
26	Copper (Cu)	mg/l	< 0.2	< 1.0
27	Lead (Pb)	mg/l	< 0.1	< 1.0
28	Mercury (Hg)	mg/l	< 0.002	< 0.05
29	Nickel (Ni)	mg/l	< 0.2	< 1.0
30	Selenium (Se)	mg/l	< 0.05	< 0.5
31	Silver (Ag)	mg/l	< 0.1	< 0.5
32	Zinc (Zn)	mg/l	< 1.0	< 3.0
33	Molybdenum (Mo)	mg/l	< 0.1	< 1.0
34	Ammonia (NH_3)	mg/l	< 5.0	< 7.0
35	DO	mg/l	>2.0	>1.0
36	Polychlorinated Byphemyl	mg/l	<0.003	<0.003
37	Calcium	mg/l	<150	<200
38	Magnesium	mg/l	<150	<200
39	Carbon tetrachloride	mg/l	<3	<3
40	Hexachloro benzene	mg/l	<2	<2
41	DTT	mg/l	<1.3	<1.3
42	Endrin	mg/l	<0.01	<0.01
43	Dieldrin	mg/l	<0.01	<0.01
44	Aldrin	mg/l	<0.01	<0.01
45	Isodrin	mg/l	<0.01	<0.01
46	Perchloro ethylene	mg/l	<2.5	<2.5
47	Hexachloro butadiene	mg/l	<3	<3
48	Chloroform	mg/l	<1	<1
49	1,2 Dichloro ethylene	mg/l	<2.5	<2.5
50	Trichloro ethylene	mg/l	<1	<1
51	Trichloro benzene	mg/l	<2	<2
52	Hexaxhloro cyclohexene	mg/l	<2	<2

Remark: The Ministry of Environment and the Ministry of Agriculture, Forestry and Fishery shall collaborate to set up the standard of pesticides which discharged from pollution sources.

(2) Water Supply and Sanitation Policy

The national policy on water supply and sanitation is approved by the Council of Ministers on 7th February 2003. It has three parts, urban water supply, urban sanitation and rural water supply / sanitation.

For the investment decisions, the urban sanitation policy clearly states that the objective is to "*ensure efficient and sustainable investment for operational sanitation systems especially installed facilities*". The policy also sets the following guidelines:

- Divide urban areas into sanitation zones.
- Divide sanitation zones into neighborhood sanitation blocks.
- Develop neighborhood sanitation systems within the block
- Develop zonal sanitation system to match and respond to the neighborhood sanitation system within the zones, and
- Develop citywide sanitation system to match and respond to the zonal sanitation systems.

For the selection of technology, the policy calls for locally applicable appropriate technology and promotes the use of separate system, particularly in new installed areas. The policy also describes in detail for choice of technologies for neighborhood, zonal and citywide sanitation systems.

Some very important guidance is available for financing and cost recovery in the national policy. These includes,

- For the construction of neighborhood or community sanitation systems, all residents in each community shall share in financing the systems, whether they use them or not.
- Public and private utilities and NGOs may provide technical assistance, funds and materials for the construction or pre-finance a part or all of the capital cost subject to full cost recovery.
- Neighborhood community members shall work out their own rules for cost sharing for operation and maintenance.
- For the zonal and citywide sanitation system, forms of financing may include government, institutions, foreign assistance and private sector finance.

Regarding management of the sanitation systems, the policy states that,

- Ministry will be in charge of financing and technology development at zonal and citywide sanitation system
- Municipal and provincial government will manage the citywide and zonal sanitation system
- Municipal and provincial government will fix the role of community for neighborhood sanitation system
- Community sanitation blocks will manage the neighborhood sanitation system

9.1.6 Donor Activity in the Sector

(1) JICA

JICA has carried out a number studies and is at present completing the construction of a major upgrade to the water supply system:

- 1996-2000, "The Study on Water Supply System for Siem Reap Region in Cambodia", provided a master plan for the water supply system and conducted a feasibility study for the urgent project of upgrading the water supply system with a capacity of 8,000 m3/d.

- 2003-2004 Basic Design Study.
- November 2004, detailed design and construction of the urgent upgrade under JICA Grant Aid. Construction has started and completion is scheduled for end of February, 2006. Initially partial service will start (60%) in 2006 and full operation is planned from 2008. The important features of this project are as follows:
  - Target Year 2008
  - Service area 425 ha
  - Design coverage 65% of domestic & public and 40% of tourism demand
  - Population served 26,000 (in 2008)
  - Unit water demand 120 lpcd (domestic, 2008), 500 lpcd (tourism, 2008)
  - Water source Ground water (1100 m^3/d x 8 wells)
  - Peak factor 1.2 (domestic/public), 1.57 (tourism)
  - NRW 15% (2008)

(2) ADB West Siem Reap Sewerage & Drainage Development

ADB is now financing "Mekong Tourism Development Project" in three countries, namely, Cambodia, Vietnam and Laos. Though main focus is sustainable tourism development, there are components of environmental improvement and human resource development. Cambodia portion of the Project (CAM-1969, loan agreement signed in February, 2003) is implemented by Ministry of Tourism (MOT) and includes environmental improvement, airport and road development, among others. One of the sub components of the project is the Siem Reap Wastewater Management Project covering 17,000 residents who live in the west bank of the Siem Reap River. The estimated cost of this sub project is US$ 3.53 million. A Project Management Unit (PMU) has been established in Phnom Penh, headed by Ministry of Tourism with a deputy director from Ministry of public works for the sewerage and drainage sub-component. In Siem Reap, a Project Implementation Unit (PIU) has been established within DPWT.

The project is already at the detailed design stage and focuses on resolving frequent flooding that occurs in the central commercial and tourist accommodation area. The flooding results in the inundation of properties by combined storm water runoff and wastewater during periods of heavy or prolonged rainfall. The Town Center Drain (TCD) on the west side of town receives raw sewage, septic tank effluent, sullage wastewater and municipal solid waste resulting in gross contamination and reduced capacity for conveyance of storm water and wastewater flow. The resulting negative impacts include: reduced public safety and access, risk to public health as well as reduced aesthetic quality of the urban environment. These negative impacts significantly reduce the tourism amenity of the area.

The main focus of the ADB project is drainage but it also includes the initial infrastructure required for the stage-wise implementation of sewerage. The project includes the following components:

- Construction of combined interceptor sewer, pumping station and wastewater treatment plant
- Construction of interception chambers to divert wastewater from existing combined sewers in the central market and old market areas.

- Cleaning and rehabilitating the existing Town Center Drain including resettlement of squatters and removing illegal buildings on maintenance right-of-way.

These trunk facilities would initially be used to relieve combined stormwater and sewage flows and would later be converted to a fully separate sanitary sewage system.

Preliminary cost estimates produced by the design consultants indicate that the total project will cost about 10 million USD excluding land acquisition. This amount exceeds the allocated budget which will only be enough to rehabilitate the town center drain. ADB is now considering an increase in funding and is expected to make a decision in December 2005. Early indications are positive and the full scope of the project will likely go ahead. Land acquisition by local government appears to be a problem and could delay the implementation. Construction was scheduled to begin mid 2006.

(3) AFD

AFD France has recently completed a feasibility study for "Urban Development of Siem Reap-Angkor". The counterpart agency is APSARA. The study focuses on providing road and drainage infrastructure in the east urban growth areas south of NR6 where development is taking place at a rapid pace. The study does not include wastewater management. The scope of the drainage study consists of:

- Identifying natural drainage patterns and defining drainage catchments
- Defining characteristics and runoff coefficients for catchment areas
- Defining rainfall-intensity-duration-frequency curves for calculating volume of runoff
- Preparing a rainfall runoff model and quantifying the volume of runoff for different return periods
- Preliminary hydraulic capacity of canals and drains.

The study has identified a number of priority projects for road and drainage improvements as well as the need for additional studies including preparation of a master plan for drainage (city wide) and a detailed hydraulic study of Siem Reap River for erosion and flood control.

The feasibility study also points out that open drains should not be used for conveying wastewater because it will contaminate water used for agriculture and could also lead to the contamination of groundwater. It identifies the urgent need for separate sanitary sewers.

(4) KOICA

The most comprehensive sewerage study completed to date is a feasibility study for Siem Reap Town Sewerage that has been carried out by the Korean engineers. MPWT has requested funding from KOICA to implement the proposed sewerage projects:

Phase I – East district	: 33 million USD.
Phase II – West district	: 12 million USD

Main features of the study are as follows:

- A single treatment plant located on East side south of the ring road using waste stabilization ponds

- Treatment capacity of 16,000 m3/day for year 2020
- Separate sewer system serving 53,000 people, covering 436 ha
- Priority is given to the East side for Phase I

The system serves an area and a population roughly equivalent to Zone 1 in the JICA master planning study. Implementation schedule and funding arrangements for detailed design and construction are not know at this time.

9.2 Sector Approach

9.2.1 Wastewater and Stormwater Characteristics

Household wastewater derives from a number of sources. Wastewater from the toilet is termed 'blackwater'. It has a high content of solids and contributes a significant amount of nutrients (nitrogen, N and phosphorus, P). Blackwater can be further separated into faecal materials and urine. Each person on average excretes about 4 kg N and 0.4 kg P in urine, and 0.55 kg N and 0.18 kg P in faeces per year. In Sweden it has been estimated that the nutrient value of urine from the total population was equivalent to 15–20 % of chemical fertilizer use in 1993 (Esrey et al., 1998). This represents a considerable potential resource that is generally underutilized.

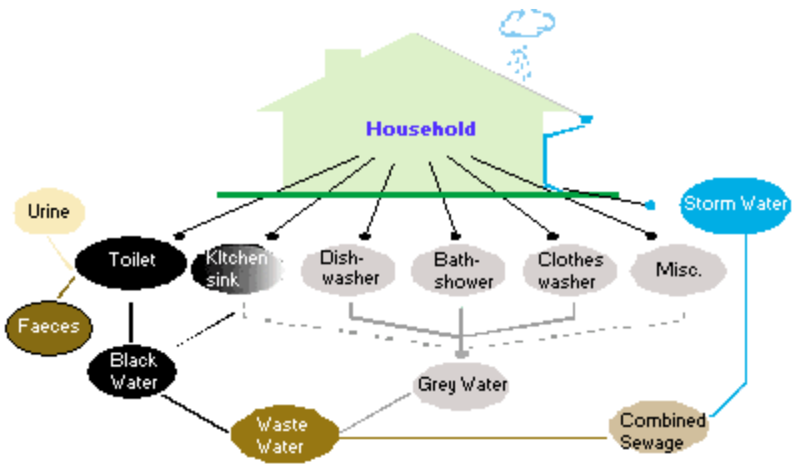

Figure III.9.3 A Range of Household Wastewater Sources (UNEP)

Greywater consists of water from washing of clothes, from bathing/showering and from the kitchen. The latter may have a high content of solids and grease, and depending on its intended reuse/treatment or disposal, can be combined with toilet wastes and form the blackwater. Both greywater and blackwater may contain human pathogens, though concentrations are generally higher in blackwater. The flow of wastewater is generally variable with peak flows coinciding with high household activities in the morning and evening, while in the night minimal flow occurs. Pollutant loads vary in a similar manner.

Stormwater in an urban area is produced from house roofs, paved areas and from roads during rainfall events. In addition, stormwater is produced from the catchment of a stream or river upstream of the urban area. The amount of stormwater is therefore related to the amount of rainfall precipitation as well as the nature of the surface. Vegetated surfaces slow the rate of runoff to stormwater and also allow rainfall to penetrate the soil whereas impervious surfaces do not and therefore produce more runoff. During a storm event, the peak flow of stormwater is higher and duration shorter with an impervious surface, while the peak flow is lower and duration longer with a vegetated surface. Stormwater runoff may contain as much solids as household wastewater depending on the debris and pollutants in the path of the stormwater runoff, although in general the pollutant load of stormwater is lower than that of wastewater.

The environmental impact of wastewater and stormwater can be substantial. Solids in both wastewater and stormwater form sediments and can eventually clog drains, streams and rivers. Grease particles form scum and are aesthetically undesirable. The nutrients N and P cause eutrophication of water bodies, with lakes and slow moving waters affected to a greater degree than faster flowing waters.

Other pollutants in wastewater and stormwater are heavy metals and possible toxic and household hazardous substances. Heavy metals include copper, zinc, cadmium, nickel, chromium and lead. The content and concentration are dependent on the pipe materials employed to convey drinking water, household-cleaning agents used, and for stormwater, the type of materials used for roofing and guttering. In high enough concentrations these heavy metals are toxic to bacteria, plants and animals, and to people. Toxic materials may also be disposed with household wastewater. These could be medicines, pesticides and herbicides that are no longer used, as well as excess solvents, paints and other household chemicals.

Spills of chemicals, particulates from motor vehicle exhausts and deposition of atmospheric pollutants can similarly contaminate stormwater. These pollutants will affect downstream receiving waters.

Wastewater and contaminated stormwater can contaminate groundwater. This is through infiltration of the wastewater or stormwater through the soil to an unconfined groundwater aquifer. Soil can filter some pollutants, but soluble pollutants (e.g. nutrients and heavy metals) and very small particles (e.g. viruses) travel with the water to the groundwater aquifer.

Stormwater runoff may contain as much solids as household wastewater depending on the debris and pollutants in the path of the stormwater runoff, although in general the pollutant load of stormwater is lower than that of wastewater.

Table III.9.2 provides a comparison of urban stormwater sources and untreated sewage in North America to those found in Siem Reap drains during dry and wet weather seasons.

Table III.9.2: Comparison of the Characteristics of Stormwater Sources and Untreated Sewage

Type of wastewater	BOD_5 (mg/L)	Suspended solids (mg/L)	Total N (mg/L)	Total P (mg/L)	Total Coliform (MPN/100mL)
Urban stormwater (1)	10-250 (30)	3-11,000 (650)	3-10	0.2-1.7 (0.6)	10^3-10^8
Untreated sewage (1)	(160)	(235)	(35)	(10)	10^7-10^9
Drain (dry weather) (2)	(80)	(300)	(5)	(5)	10^7-10^9
Drain (wet weather) (3)	(70)	(130)	(0.11)	(1)	10^4-10^6
Combined sewer overflows (1)	60-200	100-1,100	3-24	1-11	10^4-10^6

Figures in brackets = mean values; NA = not available; MPN = most probable number

(1) UNEP, Novotny and Olem, 1994; Novotny, 1995.

(2) Water quality survey Dec 2004, JICA study team

(3) water quality survey July/Aug 2005, JICA study team

There are no separate sanitary sewers therefore during wet weather the drains carry stormwater mixed with wastewater. Therefore its not surprising that stormwater runoff in drains has similar characteristics to those typical of combined sewer overflows.

9.2.2 Best Management Practices for Sustainability

(1) Integrated Waste Management

Integrated Waste Management refers to the practice of considering wastewater, stormwater and solid waste management as inextricably linked. This is in contrast to the practice of viewing each waste stream as independent and separate from the others. Critical to wastewater and stormwater management are solid wastes and wastewater produced by industry. In many instances these may not differ in characteristics from domestic wastes, consisting primarily of biodegradable organic substances. Industry, however, produces numerous types of wastes that may be toxic to the bacteria that are utilized to treat domestic wastewater. The practice in many communities is for industrial wastes to be disposed with domestic wastes and this often leads to problems.

One principle that logically emerges from adopting an integrated approach to waste management is that different types of waste should not be mixed. Solid wastes should not be dumped into stormwater drains, but should be collected, recycled, reused, or treated and disposed separately. Dumping of solid wastes in stormwater drains will not only restrict the flow of stormwater, but also contaminate stormwater. Treatment of the stormwater will involve separating the solids and other contaminants from the water. Similarly industrial wastes should be treated separately, and industrial wastewater should be pre-treated if they are to be discharged to the sewer.

A useful tool that can help towards achieving integrated waste management is the waste management hierarchy. It has been used to direct waste management towards achieving environmentally sound practice. The waste management hierarchy in its most general form is shown in Table III.9.3. In using this tool for waste management we systematically go down the list to see if step 1 (Prevent or reduce waste generation) can be implemented, before considering the next step (2) and so on. Only when steps (1) to (5) have been fully considered that we consider disposal of the waste (step 6).

Table III.9.3 The Waste Management Hierarchy
Step 1: Prevent or reduce waste generation
Step 2: Reduce the toxicity or negative impact of the waste
Step 3: Recycle waste in its current form
Step 4: Reuse waste after further processing
Step 5: Treat waste before disposal
Step 6: Dispose in an environmentally sound manner

Source: UNEP sound practices for waste management

(2) Comparison between Sustainable and Unsustainable Wastewater and Stormwater Management

In nature, waste materials are produced by living organisms (plants, animals and people). These wastes include faecal materials, leaf litter, food wastes and dead biomass. Yet streams and rivers flowing through a pristine forest, or freshwater lakes in a forest, have generally an excellent water quality. There are natural processes that purify the naturally produced wastes and provide a basis for determining environmentally sustainable management practices for wastewater and stormwater.

Discharge of wastewater and stormwater into an environment exceeding the natural purification capacity of that environment will result in the accumulation of organic materials (carbon), nitrogen, phosphorus or other pollutants that cannot be absorbed by the ecosystem constituting the receiving environment. Accumulation of organic materials will result in a high oxygen demand that cannot be met by oxygen transfer from the atmosphere and anaerobic conditions result.

In a sustainable wastewater management system, nutrients in the wastewater are reused to grow food. The liquid effluent from wastewater treatment plants is used for crop irrigation. Biosolids produced as a byproduct of wastewater treatment is stabilized and used as fertilizer. In this way there is not the need to use as much chemical fertilizer and at the same time, there is much less discharge of nutrients to the river.

In a sustainable wastewater management system greywater can be reused for watering trees and gardens. In this way there is not the need to use as much groundwater resource and the amount of wastewater can be reduced. The re-use of greywater for large water consumers such as hotels can have a significant impact on the environment.

Water conservation is also an important strategy for large consumers such as hotels. Besides preventing pollutants entering the water, water conservation means that less wastewater has to be treated. Since the size of treatment systems is primarily governed by the volume rather than the amount of pollutants in the water, a lower volume means smaller treatment plants and a corresponding capital cost. Use of less water to flush toilets belongs to this principle.

In a sustainable wastewater management system stormwater should be separately collected and treated to reduce the pollutant load in drains. The volume of stormwater runoff generated in the urban area should be reduced or at least controlled to prevent flooding and reduce the cost of increasing conveyance capacity of drains. This can be achieved by using more pervious materials for streets, sidewalks and parking areas and designing the urban landscape to provide areas such as parks or grass strips for local infiltration. Land developments which increase the amount of runoff should be required to provide stormwater detention ponds to reduce the peak flows and impacts on downstream conveyance facilities.

9.2.3 Stormwater Management

(1) General Concepts

Stormwater in an urbanized area is produced from house roofs, paved areas and from roads during rainfall events. In addition stormwater is produced from the catchment of a stream or river upstream of the urban area. The amount of stormwater is therefore related to the amount of rainfall precipitation, and the nature of surfaces, with impervious surfaces producing more runoff. During a storm event the peak flow is higher and duration shorter with an impervious surface, while the peak flow is lower and duration longer with a vegetated surface.

Natural stormwater drainage occurs in what is usually termed a catchment basin. In a catchment basin, rainwater runoff flows to a common point of discharge, and in so doing, forms a stream or flows in a drain. Crossing a catchment boundary may mean that the water has to be unnecessarily pumped, requiring an energy source. A stormwater drainage system should therefore follow natural drainage patterns and catchment basins.

(2) Rainfall

One of the most important parameters for the design of stormwater systems is the rate and volume of surface runoff to be conveyed through the system. Runoff estimates are usually based on historical rainfall data that provides frequency, intensity and duration of storm events. Rainfall data from 1988 to 2004 is available from the provincial department of water resources and meteorology MOWRAM. Rainfall data recorded at Siem Reap meteorological station is recorded over a 24 hours period and does not include the shorter duration records that are needed to develop the rainfall-intensity-frequency-duration (IDF) curves typically used for calculation of runoff.

The French Consultants ICEA carried out a detailed analysis of rainfall for their work under the AFD feasibility study for drainage in the east side of Siem Reap. They carried out a regression analysis of the 24 hour rainfall records for the years 1988 to 2003. The following 24 hour rainfall in Siem Reap for the 10, 5 and 2 year return periods is based on their analysis.

Table III.9.4 Return Period and 24 Hour Rainfall

Return period T (years)	Rainfall R (24 hr)	R(T)/ R(T10)
T1	82.3 mm	49%
T2	123.1 mm	73%
T5	149.0 mm	88%
T10	169.1 mm	100%

Return period T (years)	Bangkok R(24h)	Phnom Penh R(24h)	Siem Reap R(24h)
T1			82.3 mm
T2	87.1 mm	70 mm	123.1 mm
T5	104 mm	94.5 mm	149.0 mm
T10	123.8 mm	105.5 mm	169.1 mm

The smallest time increment for rainfall data is 24 hours and it is too large to carry out a statistical analysis of the record to determine IDF formulae. The AFD study overcame this difficulty by comparing IDF curves in Bangkok and Phnom Penh and extrapolating for Siem Reap to reproduce the 24 hour rainfall for different return periods. IDF data and hourly rainfall based on their analysis is presented in Table 1 (Appendix).

The IDF formula for Siem Reap for different return periods are as follows:

T10 $I_{rain} = 8949 \times (t + 29.51)^{(-0.98)}$

T5 $I_{rain} = 7324 \times (t + 28.20)^{(-0.97)}$

T2 $I_{rain} = 5220 \times (t + 25.39)^{(-0.95)}$

where,

I_{rain} : Rainfall intensity (mm/h)

t : Duration time (minutes)

T : return period (years)

The longer return period corresponds to a more intense rainstorm and a larger volume of stormwater. Major components of the stormwater drainage systems such as main drains, collectors and detention ponds should be designed for a storm with a 10 year return period. Secondary drains and stormwater sewers should be designed for a 5 year return period.

(3) Runoff Analysis

The AFD feasibility study derived runoff quantities by viewing the whole catchment area as a series of cascading basins. The amount of runoff that needs to be stored in each basin is calculated for rainfall events with different return periods and tabulating the water balance (Volume in, Volume out, and Volume stored). The required storage volume is the taken as the maximum value obtained.

Vr = 10 x (Rt - Inf) x C x S

Where, Vr = runoff volume (m^3)

Rt = rainfall (mm) for given a duration rainfall duration t

Inf = initial infiltration

C = runoff coefficient

S = surface area of catchment (ha)

Vout = 60 x Qout x t

Vd = discharge volume (m^3)

Qout = flow leaving catchment area (m^3/s) based on 10 (liter/s/ha)

Vs = Vr - Vout

Vs = volume of storage required (m^3)

The maximum amount that should be released (Qout) from each catchment area is fixed at 10 liters/s/ha. This value was selected because lower values (5 liters/s/ha) required too much storage volume while higher values would make downstream conveyance capacities excessively large.

The hydrological formula developed for the east side can also be used to identify preliminary requirements for storage and conveyance capacities on the west side. Key results and parameters that will be used by the JICA study team are described briefly in the following paragraphs.

Runoff coefficients and initial infiltration values set by the study are as follows:

Table III.9.5 Runoff Coefficients and Initial Infiltration

Return period	Runoff coefficient C	Initial infiltration
T1	0.6	10mm
T2	0.75	10mm
T5	0.8	10mm
T10	0.85	10mm

These reflect the relatively rural nature of development where large portion of the surfaces are pervious.

Based on the above parameters the following unit storage volumes (for 1 hectare) were determined whereby rainfall duration t corresponds to the time for peak flow on the unit hydrograph and Vs corresponds to the maximum storage required.

Table III.9.6 Unit Storage Volumes

Return period	Runoff C	Rain Duration t	Vs at t	Td	t + Td
T1	0.6	4.3 h	1035 m^3/ha	28.7 h	1.4 days
T2	0.75	3.9 h	810 m^3/ha	22.5 h	1.1 days
T5	0.8	3.3 h	565 m^3/ha	15.7 h	0.8 days
T10	0.85	2.2 h	240 m^3/ha	6.6 h	0.4 days

Td = time required to discharge stored volume assuming 10 liter/s, t = time to peak of unit hydrograph

From a hydrological perspective there is very little difference between east and west except for the relatively small central and old market areas. Therefore the same parameters are used to carry out a preliminary analysis of drainage in the west.

(4) Collection and Conveyance

1) Comparison Between Pipe and Open Drains

In Siem Reap most stormwater flows through the landscape's natural drainage system. Piped stormwater collection was developed in the city's central core to overcome odor and improve aesthetic appearance because wastewater is disposed with stormwater.

Piped drainage allows more land area for road and footpaths however the system no longer functions properly because it has been damaged by construction activities and has become clogged with solid waste which cannot be easily removed.

In most urban areas of Siem Reap, open drains will be more suitable than pipes for conveying separated stormwater. Open drains have many advantages:

- easier to clean and remove rubbish
- easier to repair and maintain
- natural detention storage to reduce peak flows
- natural infiltration to reduce amount of stormwater
- natural treatment and removal of pollutants

Stormwater should be collected in pipes where more than 40% of the land area is developed i.e. covered by pavement and buildings. This will be mainly in the central core area of the City on the East and West side.

2) Need for Stormwater Storage

Rainfall intensity is relatively high in Siem Reap therefore the volumes of stormwater that must be conveyed are large. The hydraulic capacity for drainage is limited by the relatively flat natural gradient and high water levels at the outlet downstream (Tonle Sap).

Pumping could improve the situation but this is not a sustainable option since the energy costs and the probability of mechanical failure are very high.

Hydraulic capacity can be improved by cleaning existing drains and providing additional drains in developing areas however this alone will not be enough. The only practical way to prevent flooding is to provide stormwater detention (storage) facilities scattered throughout the drainage system, especially in upstream catchments. Storage would consist of:

- Small off-line Detention ponds
- Larger reservoirs
- In-line storage in canals and drains

(5) Treatment and Re-use

The treatment of stormwater means the reduction and removal of pollutants from the water. The first principle to bear in mind therefore is to prevent pollutants from entering the water in the first place. In the case of stormwater the surfaces through which stormwater runoff passes over should as far as possible be free from solids and other wastes. Thus the collection of solid wastes is an important part of stormwater treatment as is the separate collection of wastewater and stormwater.

When stormwater is collected in a combined sewerage system it is treated with the wastewater, though treatment is not effective during peak heavy stormwater runoff periods resulting in combined sewer overflow (CSO) that is not treated. The implementation of a separate wastewater collection system will provide an opportunity to return some stormwater flow path to its more natural state to improve urban amenity value.

Separately collected stormwater is generally treated by passing it through a settling basin to remove solids (Figure III.9.4). The retention time in the settling basin is designed so that solids can settle in say 20 minutes for a one in five year storm-event. For storm-events less than the design value, removal efficiency is greater, while for storm-events greater than the design value removal efficiency is lower. Mechanical devices have been developed that can trap gross solids. Both settling basins and mechanical traps need to be cleaned regularly to maintain solids removal efficiency.

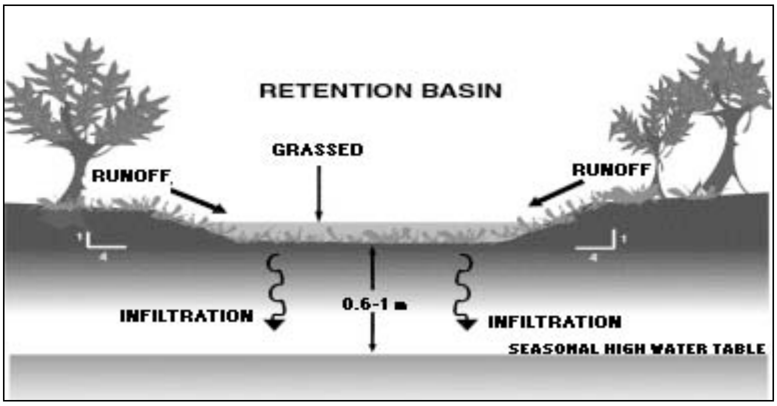

Figure III.9.4 Stormwater Treatment in Retention Basin (UNEP)

Naturally landscaped stormwater drains can help filter out fine sediments through the action of vegetation slowing down the flow and trapping solids. Permeable surfaces allow rainwater to percolate into the soil, thus treating the water and at the same time reducing the amount of runoff. Pavements can be designed and manufactured for this purpose. Directing runoff to vegetated area (rainwater harvesting) can reduce down-stream flow and reuse the water for maintaining plant growth. Storing water in ponds can delay its ultimate flow to water environments to improve flow management and hence reduce the frequency and extent of flooding. At the same time ponds can also generally remove pollutants (particulates and oils) prior to the water reaching a river or lake, while creating amenities such as wetlands, waterfowl habitats

Used judiciously these management techniques can treat stormwater locally (at source). Applying these on a sub-catchment scale (site), or whole catchment scale (region) can reduce flooding and the undesirable impacts of stormwater, while at the same time improve the amenity value of the landscape.

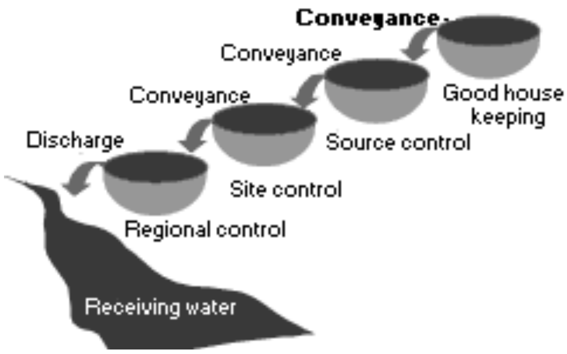

Figure III.9.5 Stormwater Management Train (UNEP)

(6) Approach for Improvement

1) Restore Capacity of Existing Drains

Improved maintenance is the simplest way of restoring drainage capacity. Therefore in the short term drainage can be improved by removing vegetation, accumulated silt and garbage.

Existing drains should be properly graded starting at the upstream end of the system and following a consistent slope to the downstream end. Main drains should be lined with concrete to improve ease of maintenance and hydraulic capacity.

2) Provide Additional Drainage Capacity

Additional drains and culverts are required to convey stormwater across the NR6 towards outlets to the south.

3) Treat Urban Stormwater

Urban stormwater is polluted because drains are full of solid waste and used for wastewater disposal. The implementation of separate sanitary sewers in parts of the urban area will help reduce the level of pollution in drains however the implementation of separate sewers will take many years. Stormwater should therefore be channeled to detention ponds where it can receive some form of natural purification before being released to the natural water environment or used for agricultural irrigation.

4) Redirect Stormwater from the Urban Core Away from the Siem Reap River

For areas immediately along the Siem River (within approximately 100 to 150m) the obvious solution is to provide stormwater outlets directly to the river. However this solution can have a negative impact on pollution levels in the river if separate sanitary sewers are not installed. Therefore it is better to divert stormwater away from the river.

5) Provide Storage in Upstream Reaches to Minimize the Impact of Runoff on Downstream Areas.

Large land development zones such as the APSARA hotel zone should be designed to store all stormwater runoff to limit the impact on downstream areas. Hotels in these zones should minimize the use of impervious areas to limit runoff and should be required to recycle stormwater for gardening and landscaping instead of pumping valuable groundwater resources.

The incidence of flooding can be reduced by providing storage in upstream reaches and at different points along the drainage system. Storage capacity can be “in-line” provided in wide canals such as those constructed along the boundaries of the APSARA hotel zone. Storage can also be “off-line” in detention ponds however it will likely prove difficult to find a suitable location where gravity will be feasible.

9.2.4 Drainage Infrastructure Requirements

(1) East Side of Siem Reap River

The AFD has recently commissioned a feasibility study for drainage in the East sector which is experiencing rapid population growth. The study included a comprehensive hydrological and hydraulic analysis including the following components:

- Statistical analysis of rainfall and determination of IDF curves
- Characterization of catchment basins
- Hydrological analysis to determine volumes of stormwater to be conveyed and stored
- Hydraulic analysis and preliminary sizing of drains and culverts

As indicated in the study the East sector can be divided into four major catchments as shown in Figure 2 (appendix):

- The area upstream of the APSARA hotel and cultural zone, bounded to the North by the Siem Reap River and to the south by the Khmer dike and canal. During high water levels the river flows overland through this catchment area. (shown as BV 1 to 5,
- The APSARA cultural and tourist zone, oriented along an East West axis, and perpendicular to the natural drainage pattern. A number of major arterial roads have already been constructed and these include very wide ditches that are intended to be used for in-line storage of stormwater runoff. (shown as BV6 to BV14)
- The urbanized area north of and along NR6. Drainage in this area is blocked by NR6 and there are a number of serious hydraulic bottlenecks created by the lack of culverts crossing the NR6. The road is a major obstacle to the natural drainage of stormwater and causes chronic flooding. (shown as BV 15 to BV29)
- The area south of NR6 which is at present developed mainly along the river. This future growth area is traversed by many roadside ditches and irrigation canals that cross each other. Stormwater collection pipes 1000mm ND have been installed in parts of the urban and non-developed areas but the installation has not been systematic.

1) North East Sector

Stormwater volumes to the north of NR6 are shown schematically in Figure 3 (Appendix). Conveyance capacities are based on storing peak stormwater flow in the Khmer Dike and large linear ponds built along the boundaries of the APSARA hotel zone. The storage volumes required for storms with different return periods are as follows:

Table III.9.7 Volume of Storage Facilities in North-East Sector (m^3)

Storage facility	catchment	T2	T5	T10
Khmer dike	BV3 to BV5	768,965	1,102,410	1,403,635
DNO	BV2 & BV6	247,980	367,540	477,340
DNE1	BV7 & BV8	402,845	577,530	737,955
DNE2	BV9	402,845	577,530	737,955

Assumes outflow of 10 liters/s/ha from each catchment area

Water levels in the Khmer Dike vary between 0.63m for T2 and 0.85m for T10. Given these relatively shallow depths the feasibility study recommends rehabilitation of the Khmer Dike embankments to provide protection against a 10 year storm. The dike plays an important role in protecting the APSARA hotel zone located downstream and to prevent flooding south of the NR6.

Dimensions are also given for proposed storage basins DNO, DNE1 and DNE2 because these large facilities are within the APSARA hotel zone and planners will need to make provision when allocating land to developers. Assuming a protection level equal to a 10 year storm the dimensions are as follows:

Table III.9.8 Dimensions of Storage Facilities in North-East Sector

Storage	Depth of water	length	Width
DNO	1.15m	1250m	380m
DNE1	1.15m	5000m	145m
DNE2	1.15m	5000m	145m

Total storage requirements for areas between the canal and NR6 are identified as follows:

Table III.9.9 Storage Volumes Required between Canal and NR6

Return period	Vs (m3/ha)	Vs m3
T10	1035	2,657,880
T5	810	2,080,080
T2	565	1,450,920

Total area: 2568ha; Qout= 10 liter/s/ha

Details of proposed storage facilities DSO, DSE1 and DSE2 are not provided in the report. Their location and size will need to be determined during project design stages.

2) South East Sector

Stormwater volumes to the south of NR6 are shown schematically in Figure 4 (Appendix). Conveyance capacities are based on providing dynamic in-line storage or off-line storage capacity to control runoff from each catchment.

A number of options for how to organize the drainage have been explored in the feasibility study. The main problem is to decide how much stormwater should be conveyed to the proposed treatment pond in Cheavs Commune. A final decision will be made at the next stage during the proposed AFD master planning study.

For the time being the plan is to minimize the capacity of canal C21 therefore only the flow from small rain events would be conveyed towards Cheavs Commune. The flow from large storm events would be directed to proposed canals CT1 and CT2 with outlets to the Siem Reap River. A detention pond will be required at the junction of C10 and C21 to control and divert excess flows towards CT2.

3) Priority Projects

Priority projects for drainage proposed in the AFD feasibility study in are listed in Table 2 (Appendix):

- Three major culverts to convey flows across the NR6
    - D2, (2 x D1200mm)
    - D7, (C2.50m x 1.50m
    - D10, (C5.70m x 2.40m)
- A canal along Cheavs Commune Road that will convey storm water to a lagoon somewhere in the South East. The lagoon would provide primary treatment for low intensity rain events before discharging storm water to irrigation canals leading to the Siem Reap River
    - Open Canal C10: 1850m long, 8.0m bottom width, 2m depth
    - Open Canal C2: 3850m long, 3.50m bottom width, 2m depth

- A canal to divert flows from the market area
    - Open canal C20: 1500m long, 3.00m bottom width, 1.5m depth.
- A number of roadside ditches next to proposed new roads.

The two outlet drains that will relieve excess storm water flows to the Siem Reap River have not been identified as priority projects but will need to be constructed in order for the scheme to work properly.

- Canal CT1: 1,800m
- Canal CT2: 3,400m

Surprisingly the proposed storage facilities are not included in the list of priority projects. Presumably these will be added to a second round of projects after the proposed master planning study has determined the details. Proposed priority projects will be constructed early 2007.

(2) West Side of Siem Reap River

1) Catchment Areas

Approximate catchment areas have been determined by field observations, location of natural drains and interpretation of topographic maps with contours of 1.25m intervals produced under the present JICA study. Catchment areas are shown in Figure 5 (Appendix).

A number of agricultural irrigation canals crisscross the study area and it is impossible to separate them from the drainage system. Some of the canals are fed from the Western Barray and others are fed from Siem Reap River. Therefore the network of canals and drains always has a base flow even in dry weather which reduces the capacity for drainage of stormwater. A detailed hydraulic study will be required in order to determine how the canals can be reorganized to improve drainage.

Catchment S1: this large catchment area straddles the APSARA protection zone and is mostly undeveloped. There is an old irrigation canal, shown as C1, which was fed from the Angkor Wat. This canal runs perpendicular to the NR6 and crosses at the Goldiana Hotel. Flow in the canal was interrupted by the construction of roads and the hotel which is actually constructed over the canal. Drainage from ditches along NR6 is discharged to the old canal on the south side of NR6 and flow is accumulated in a small pond that has no outlet.

Catchment S2: this is a large catchment area that is mostly located in the APSARA protection zone. There is a main irrigation canal, shown as C2, which is fed from Angkor Thom. The canal feeds many distribution canals including one that crosses into catchment S1. The main canal runs south and crosses NR6 at the ring road junction where it continues to flow in ditches along the ring road. The quantity of water discharged is unknown but the base flow appears to be significant.

Canal C3: South of NR6 there is an old irrigation canal that still conveys water to agricultural areas west of the ring road. The source is the Western Barray and the quantity of water is unknown. The canal has been truncated by the ring road and whatever water is not used for agriculture is intercepted by road side ditches along the ring road and conveyed south of the city. Extensive flooding occurs at this junction because the ring road drains do not have sufficient capacity to handle flows from canals C2 and C3.

Canal C4: An old irrigation canal south of the city has an intake from Siem Reap River at the crocodile weir. It feeds irrigation canals in catchment IX to the south and in Pou Bos west of the ring road. The canal has been truncated by the ring road where a culvert structure has been provided. Most of the flow cannot cross over to the other side of the ring road and is now directed to the south in drains along the ring road. Irrigation canal C4 is the main outlet for the city's stormwater drains but it has limited hydraulic capacity because it is full of river water.

2) Summary of Proposed Improvements

Proposed drainage improvements are presented in Figure 6.

Table III.9.10 Proposed Drainage Improvements - West

Catchment	Proposed improvements
Upstream NR6	• Provide stormwater storage facilities to relieve peak flows and protect downstream areas.
VI	• Provide stormwater relief sewer along Samdach Tep Vong St to divert flows away from the Town Center Drain
VII	• Provide new West Drain to increase storm drainage capacity and provide an outlet for Catchment VI. • Provide offline storage to reduce peak flows and control runoff
VIII	• Divert canal C3 before it reaches the ring road • Divert excess stormwater from the ring road drain to storage pond
X	• Provide new storm relief sewers in the old market area to divert flows away from Siem Reap River. Outlet to existing irrigation canal C4
At NR6	• Provide large box culverts at three locations to relieve flooding on north side • Provide smaller culverts at 250m intervals. • Provide storage ponds along NR6 within the 50m allowance.
Downstream	• Provide stormwater control structure to distribute flow at outlet of western drain • Divert irrigation canal C4 to catchment IX

These alternatives will require detailed hydraulic analysis and topographical surveys to determine feasibility before proceeding to the project design phase.

3) Runoff and Stormwater Storage

Runoff and storage calculations have been carried out using the same assumptions and parameters that were used in the AFD feasibility study for the east side. The method of calculation assumes that storage will be provided to limit the peak runoff and reduce the size of conveyance facilities in downstream reaches of the drainage system. Storage is fundamental to the stormwater management strategy. Without storage the flows will exceed the capacity of low gradient drains.

Storage requirements for different return periods and the amount of outflow from each catchment area are presented in Table 3 (appendix) and summarized below (Table III.9.11).

Table III.9.11 Volume of Storage Facilities - West Sector

Catchment area	Storage Volumes (m3)		
North of NR6	T10	T5	T2
S1	435,314	341,010	237,865
S2	447,722	350,730	244,645
V	127,944	100,227	69,911
VI	45,851	35,918	25,054
VII	53,650	42,028	29,316
VIII	62,040	48,600	33,900
South of NR6	T10	T5	T2
VI	105,619	82,738	57,713
VII	157,478	123,363	86,050
VIII	193,226	151,366	105,583
IX	188,116	147,364	102,791
X	79,719	62,449	43,560

Assuming runoff is controlled to 10 liter/s/ha.

The calculations indicate that a significant amount of storage will be required north of NR6 to protect the south west sector of the city from flooding. Locating the storage may be complicated by difficulties in land acquisition. Where possible, dynamic storage capacity should be provided in roadside drainage ditches and along canals.

The construction of an arterial road is proposed parallel to and north of NR6. A small amount of storage could be provided in wide ditches along each side of the road similar to those constructed along roads in the north east sector (two ditches 1500m long, 1.25m water depth, base width 2m, and side slopes 2:1 would provide 16,000m3 of storage). Other possibilities include storage ponds along both sides of NR6. These could be designed as part of urban landscape improvement project contemplated by APSARA.

Additional storage facilities (shown as S1 and S2) will be required further upstream to control discharges. There is also the possibility of providing dynamic storage along canal C1. Detailed feasibility study is required to determine the required volume, location and arrangement of storage basins. The study would include detailed topographic surveys, hydrological and hydraulic analysis.

4) Town Center Drain (TCD)

Runoff calculations for the present TCD are presented in Table 4. Stormwater volumes are based on a 10 year storm. The calculations include stormwater from catchment V which is at present conveyed to the TCD by a culvert crossing NR6. Assuming that flow in the upstream catchment is controlled the flow in TCD varies from 1.49 m3/s in the upper reaches to 2.58 m3/s at the downstream end. Assuming a depth of water of 1m, a slope of 0.1%, and side slopes of 2:1 the drain would need a top width of 4.3m at the upstream end and a top width of 5.5m at the downstream end.

The existing TCD has much smaller dimensions. Furthermore, there is at present very little storage capacity in the upstream reaches. This leads to the conclusion that runoff exceeds hydraulic capacity of the Town Center Drain as confirmed by the frequent flooding of areas along the drain.

The drain can be enlarged as proposed under the ADB project. However there are limitations to how much additional capacity can be provided because housing in several areas has encroached to the edge of the drain.

Flows in the TCD could be reduced by diverting catchment V directly to the Siem Reap River upstream of NR6. However there is concern that such a proposal would increase pollutant levels discharged to the river so this option is rejected. Diversion of catchment VI to a new western drain is proposed as the only feasible solution. This would relieve flows in the TCD and help reduce the incidence of flooding.

5) TCD Stormwater Relief Sewer

The piped stormwater system in the central area is plugged with silt and solid waste. It has been poorly constructed and is severely undersized. It will therefore be necessary to replace it with a completely new system. The drainage system in catchment VI should be reorganized to discharge stormwater flows to the proposed Western Drain.

The first step in reorganizing the system can take place when the separate sanitary sewer system is constructed. At this time separate stormwater collection pipes can also be installed with provision for extending the outfall to the western drain when it is constructed.

Preliminary calculations using the rational method indicate that the size of the relief sewer would vary from 1000 to 1400mm ND for a 10 year storm.

Road grading and rain gutters in areas along Shivata road must also be improved and more curb inlets are required, properly located at all low points. This component is not included in the present ABD project and should be included in the sewer separation program in order to reduce localized flooding.

6) Storm Sewers in Old Market Area

Storm sewers in the old market area are also in poor condition and undersized. A new stormwater relief sewer 1000mm ND is proposed along Shivata road and road number Krom Market St. Storm sewers in the old market should be reorganized to flow south into the proposed relief sewer. The relief sewer will alleviate flows in the TCD and flooding in the old market area.

The relief sewer would be discharged south of the irrigation canal C4 (crossing under the canal). The discharge will be to irrigation canals parallel to Krom Market St and the specific point will depend on topographic elevations confirmed at time of detail surveys.

7) Western Drain (WD)

A new drain is proposed to serve the west growth area and convey flows from north of NR6 to the south. Runoff collected along both sides of NR6 should be directed to this new drain. The drain will also become the main drain for future residential developments in the urban growth area to the west.

Runoff calculations and dimensions for the proposed drain are presented in Table 5. Stormwater volumes are based on a 10 year storm. The calculations include stormwater from catchment VI which is at present conveyed to the TCD. Flow varies from 4.73 m3/s in the upper reaches (north of NR6) to 7.72 m3/s at the downstream end. Assuming a depth of flow of 1.25m, a slope of 0.1%, and side slopes of 2:1 the canal would need a top width of 6.5m at the upstream end and a top width of 9.0m at the downstream end.

At the downstream end the western drain joins irrigation canal C4. Canal C4 will not have sufficient capacity to handle increased flows therefore a storage pond is proposed at this location. The pond will store excess water, sending smaller flows to C4 (towards Pou Bos) and excess amounts to areas downstream.

The flow in canal C4 coming from the river will be diverted by a new control structure placed at a point just east of the Western Drain junction and just west of the Town Center Drain. During wet weather the flow in canal C4 should be stopped at the river intake. During dry weather the proposed control structure would ensure that sufficient flow is conveyed to irrigation in Pou Bos. It should be noted that the construction of the wastewater treatment plant will also provide Pou Bos with treated effluent that can be used for irrigation. The treatment plant will therefore greatly reduce the need for water from canal C4.

8) Irrigation Canal C3

The canal used to bring water to agricultural plots which are now part of the urban growth area inside the ring road. In fact the irrigation now terminates in the drain that borders the ring road. This is causing problems with drainage because it is sending too much water into the roadside drain. Therefore it is proposed to divert the flow slightly west of the ring road. The flow can be sent into upstream distribution canals or diverted to a storage facility as shown Figure 6. Furthermore it is noted that a substantial flow is coming into the ring road drain from upstream catchments and irrigation canals north of NR6. Part of this flow could also be diverted to the proposed storage facility to relieve flows in downstream sections of the ring road drain.

9) Culvert Crossing NR6 and Ring Road

A number of new culverts will be required to convey flows across the NR6 to relieve chronic flooding. Large culverts will be required at three locations:

- D1: town centre drain, 1.24m3/s, 2 x 1200mm ND
- D2: Western drain at Goldiana Hotel, 4.73m3/s, C4.0m x 1.5m
- D3: Ring road at NR6, 4.93m3/s, C4.5m x 1.5m

A number of smaller culverts, 1 x 1200mm ND, should be placed at 250m intervals to allow flow to pass from north to south.

(3) Additional Drainage Studies Proposed by AFD

The AFD feasibility study has identified the need for a more detailed and comprehensive City wide master planning study for drainage including the need to study the Siem Reap River in order to preserve and improve it as tourism amenity. AFD plans on funding the following studies as part of the funding allocated to the implementation of priority:

2) Siem Reap River Hydraulic Study:
    - Erosion, sediment transport and bank stability study
    - Water quality study
    - Hydrological analysis
    - Hydraulic modeling and analysis
    - Socio-economic analysis
    - Management and protection action plan
3) Storm water runoff and management to reduce flooding in East and West districts
    - rainfall and hydrological analysis to determine volumes of stormwater
    - hydraulic analysis and modeling of drains: to identify capacities required for existing and post urbanization conditions, and to identify the impact of improvement projects
    - Recommendations on location and sizing of new drains and culverts
    - Recommendations on the need for in-line storage or detention ponds to reduce peak flows
4) pollution control and stormwater management
    - Potential impact of urban storm water runoff on surface water quality
    - Identifying the need for stormwater treatment
    - Potential impact of using open drains on groundwater quality
    - Investigate the need for storm water treatment

9.2.5 Wastewater Management

(1) Defining the Service Area

Separate sanitary sewers are proposed for part of the urban area which meets the following criteria:

- Areas with medium to high population density
- Areas served by the water supply system
- Areas with a large concentration of hotels and tourism activity

The implementation of a separate wastewater collection system improve sanitary conditions in densely populated areas and will provide an opportunity to return some stormwater flow path to its more natural state to improve urban amenity value.

Population framework indicates that most of the urban growth will occur within the perimeter of the ring road where densities will be sufficiently high to justify some form of wastewater management by a public authority. Therefore the ring road is used to define the urban boundary with the exception of a long narrow strip along the West section of NR6 where there is a high concentration of hotels.

The “urban area” has been divided into 3 service zones for the purposes of planning for wastewater management. The main parameter used to define the zones is population density for 2020. Furthermore Zone 1 corresponds to the area serviced by the newly constructed water supply system where the amount of wastewater is expected to increase significantly in the very near future. The target areas are shown on Figure 7 (Appendix).

Peri-urban areas outside the ring road are expected to retain some of their rural character and it is assumed that these areas would continue to rely on traditional

on-site sanitation methods at the household level.
Private housing schemes located outside the ring road to the East, south of NR6 are also excluded from the wastewater management zone because they are too far from the city to service. Furthermore the location of these schemes is difficult to predict since they are not following any formal land development plan. These housing schemes are generally lower density developments with larger plots suitable for on-site treatment using septic tank systems or small scale community treatment plants.

The APSRA hotel zone is not included in the target service area. The hotels in this area will be very large private sector developments. Following the principles of good environmental stewardship, the hotels should be required to provide their own small scale advanced wastewater treatment plants as well as systems to recycle all grey water for gardening. Effluent from small scale treatment plants can be discharged to a polishing pond. APSARA has planned a large drainage canals to the north and south of the special hotel zone. These canals would make ideal polishing ponds if they are designed as a series of interconnected lotus ponds.

(2) Wastewater Servicing Options

A review of the different servicing options is required before deciding on an appropriate wastewater management scheme for Siem Reap. There are generally three main types of servicing systems for wastewater management:

- On-site
- Cluster
- centralized

1) On-site Systems

On-site wastewater servicing refers to any system where wastewater produced on the site is treated and returned to the ecosystem within the boundaries of that site. In Siem Reap City, the majority of households and hotels use on-site systems consisting of septic tanks. Only a small percentage of households use pit latrines.

Not all residues are dealt with on-site. Sludge (septage) from the on-site treatment system is removed off-site and returned to the ecosystem in an approved manner. Most on-site sanitation systems do not cater to sullage (i.e. wastewater from sinks, showers etc.) Sullage is discharged to drains.

2) Cluster Systems

Cluster wastewater servicing systems are community systems for two or more dwellings. They are generally much smaller in scale than a centralised system. The wastewater from each cluster of dwellings may be treated on-site by individual septic tanks before the septic tank effluent is transported through alternative sewer systems to a nearby off-site location for further treatment and ecosystem re-entry. In other situations the full wastewater flow from each cluster may be reticulated off-site to a local treatment site. As in the case of an on-site system, sludge or bio-solids may be managed independently.

3) Centralized System

In a centralized system all wastewater is collected at its source and then transported (through sewer pipes) to a central site for treatment. After treatment, the resulting effluent and sludge (bio-solids) is discharged at a particular point, thus re-entering the ecosystem. As in the case of cluster systems, some treatment may occur on-site prior to the wastewater being transported to the central treatment site.

Although centralized sewerage is the most expensive sanitation option it has proven long-term advantages particularly in densely populated urban areas.

The operating costs of the various servicing systems need to be considered when choosing an appropriate technology. For centralized sewerage, the cost of pumping must be considered with who is going to pay for it.

4) Selection of Servicing Systems

A comparison of the various servicing systems is presented in Table III.9.12

On-site sanitation is often (and should be) the first option when considering a sanitation intervention. Such systems have distinctive advantages because they are individual systems so the disposal of faecal materials is dispersed over a wide area. One of the main disadvantages with centralized facilities is that when they go wrong, the resulting problems can be very acute.
Septic tanks are already widely used in Siem Reap however; effluent disposal by percolation to soil is not always possible in high density areas where space is not available. In other areas the groundwater table is too high and soil has poor permeability. As a result septic tank effluent and sullage are most often discharged to stormwater drains. This can be a public health problem mainly in high density urban areas and hotel zones where wastewater disposal is more concentrated.

A centralized servicing scheme would be more appropriate for the high density urban core and tourist areas. These are identified as **Zone 1**. Other areas would continue to use septic tanks. In time, as population densities and water consumption increase, it will become feasible (technically and economically) to connect these other areas into the centralized system. For example, areas identified as **Zone 2** will likely need to be converted by 2020.

Table III.9.12 Proposed Servicing Arrangement

	2012	**2020**
Zone 1	Centralized	Centralized
Zone 2	On-site	Centralized
Zone 3	On-site	On-site
APSRA hotel zone	On-site or Cluster	On-site or Cluster

(3) Wastewater Collection Systems

A sewerage system collects wastewater and can be in the form of blackwater separated from greywater, or mixed with it (sewage). Gravity is used wherever possible to convey the wastewater. The principle of using gravity as the driving force for conveying wastewater in a sewerage system should be applied wherever possible, because this will minimize the cost of pumping. Natural stormwater drainage occurs in what is usually termed a catchment basin. In a catchment basin, rainwater runoff flows to a common point of discharge, and in so doing, forms streams and rivers. Crossing a catchment boundary may mean that the water has to be unnecessarily pumped, requiring an energy source. A wastewater sewerage system should therefore be within a stormwater catchment basin.

1) Comparison between Combined and Separate Sewers

Sewerage systems are either combined or separate. Combined sewerage carries both stormwater and wastewater, while separate sewerage carries stormwater or wastewater separately. Recent trends have been for the development of separate sewerage systems. The main reason for this is that stormwater is generally less polluted than wastewater, and that treatment of combined wastewater and stormwater is difficult during heavy rainfalls, resulting in untreated overflows (commonly termed combined sewer overflow, CSO).

In practice there is usually ingress of stormwater into wastewater sewerage pipes, because of unsealed pipe joints, and unintentional or illegal connections of rainwater runoff. Conversely there may be unintentional or illegal wastewater connections to stormwater sewerage.

A combined system could help relieve some of the stormwater drainage problems however the incremental cost of pumping and treating stormwater are not sustainable or economically justifiable. It will be more cost-effective in the long-term to adopt a separate sewer system.

Table III.9.13 Comparison of Separate and Combined Sewerage Systems

Sewerage system	Advantages	Disadvantages	Suitability
Separate	• Sewers are of smaller size • Only sanitary sewage is treated • Lower volume of wastewater to be lifted and treated therefore lower investment and operating costs. • Can accommodate septic tanks effluent	• Two sets of sewers may prove to be costly unless drainage is predominantly in open drains • Stormwater is discharged without treatment and may carry a heavy pollutant load (first flush).	• Economical in flat areas as excavation is not as deep. • Desirable in areas that do not have any sewerage system.
Combined	• Only one set of pipes may prove to be more economical in large urban areas where open drains are not feasible	• Increased load on sewage treatment plant • Large volumes to be pumped therefore high operating costs • Heavy rains causes frequent overflows of untreated sewage to drains and potential backflow into house connections • Low sewage velocities during dry season leading to blockages and odour nuisance.	• Where rainfall is uniform throughout the year • Where pumping is required for both sanitary and stormwater drainage. • Where sufficient space is not available for two separate sets of sewers. • Where combined systems already built and operated.

Table III.9.14 Comparison of Wastewater Servicing Systems

Servicing system	Description	Advantages	Disadvantages	Suitability
Fully on-site	• Treatment of domestic wastewater from private households and tourist facilities in individual or communal septic tanks (up to about 50 households). • Discharge of effluents to soak pits where conditions are suitable or to storm water drains where groundwater table is too high	• Simple and durable • Requires little space because it is underground. • Long-term sustainability, reliable with minimal maintenance and operational requirements	• Low treatment efficiency (25 to 50%). • Septic tanks do not remove pathogenic material therefore discharge to drains will contaminate the environment. • Septic tanks need regular de-sludging and treatment of septage. • Can be expensive in urban areas	• Appropriate in rural areas and urban areas low to medium density (< 80 ppha)
Cluster	• Collection of domestic wastewater from private households or hotels, and conveyance to a small scale treatment plant located near the place of generation.	• Community participation in decision making and O&M. • Can be implemented quickly and will probably be sustainable.	• Unit costs are relatively high and typically benefits mostly upper and middle class people.	• In the special hotel zone • In special housing schemes or small high density communities inside or outside the urban area
Combination of on-site and centralized	• Individual or communal septic tanks intercept solids and provide pre-treatment. Septic tank effluent is collected in a small diameter pipe network and conveyed to a collector sewer • Conventional sewerage for trunks and primary collectors. • Low cost "simplified sewerage" also known as condominium or in-block sewerage in neighbourhoods where streets are narrow and access for construction will be difficult.	• On site component acts as a pre-treatment to the central system therefore size of central treatment can be reduced • Septic tank effluent no longer discharges to drains thereby improving downstream environment. • Simplifies construction and reduces the capital cost of installing sewerage pipes.	• Septic tanks require de-sludging and sludge treatment facility. • Pipe may become blocked (solid waste). • Septic tank effluent requires treatment facility. • Collection system will require pumping.	• Best used to collect effluent where septic tanks already exist. • Suitable for medium density urban population 80 to 150 ppha where water supply is at least 60 lpcd.
Fully centralized	• Collection of all household wastewater and transportation using conventional sewerage to a central treatment facility	• Better health and better downstream environment if properly operated and maintained. • Lowest cost option in for higher density urban areas • Management and control are more easily centralized	• Will take a long time to build. • Breaks down quickly unless there is adequate capacity for O&M • When large centralized schemes do not work the resultant pollution and health problems are often severe. • Reluctance to connect and poor cost recovery can jeopardize sustainability. • Collection system will require pumping.	• Suitable for high density urban areas (>150 ppha) where water consumption is at least 100 lpcd.

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The ADB is in the process of preparing a detailed design for the construction of an interceptor sewer that will in the short term convey combined wastewater to a treatment plant. The project has selected a combined interceptor sewer as the least cost solution for providing immediate relief of flooding along the town center drain. The interceptor sewer is the first step in a longer term program and is the backbone of the future separate sanitary sewer system. The ADB design concept is based on gradually eliminating stormwater from the interceptor by installing separate sanitary and stormwater sewers throughout the service area in subsequent project stages.

2) Types of Sewerage Systems

Wastewater sewerage systems can be classified into three major types:

- Conventional sewerage
- Simplified sewerage
- Settled sewerage

Where wastewater treatment is centralized, the wastewater needs to be collected and transported to the treatment plant. This is done by a pipeline or network of pipelines (sewers) that collect wastewater flows from all dwellings in the community. Energy to transport the wastewater may be by gravity, pumping or a combination of pumping and gravity, depending on topography, layout and economics. For systems involving some on-site pre-treatment (such as a septic tank), reticulation is often done by small diameter pipeline systems.

(a) Conventional Sewerage (CS)

Conventional sewerage is also termed deep sewerage because the sewerage pipes are laid deep beneath the ground. Pumping is generally required at various stages of the sewer pipe network, especially if the landscape is fairly flat. The larger the population served by the sewerage system, and the longer the planning horizon is to cope with future population increases, the larger the diameter of the final pipes becomes. The costs of the pipes, inspection manholes, pumps and pumping stations and their construction/installation are therefore high. The costs of operation and maintenance are correspondingly high because of very conservative design assumptions.

In the conventional system, on-property sewer lines (100 mm diameter) from household are connected to street sewer-lines (minimum 150 mm diameter), which are reticulated in straight lines between manholes that provide access at all changes in direction. Manholes are used at all street reticulation connections to main collecting sewers, and again where trunk sewer connections are made. The minimum sewer sizes are based on design rules for use of traditional clay and concrete sewer pipes, and on the self cleansing gradients necessary to scour out any sand and sediment entering the sewerage system.

The maximum distance between manholes historically has been determined by the need to mechanically clear obstructions using rods, which becomes difficult for distances over 90–100 meters. Manholes are a significant proportion (15–20%) of the total sewerage costs. They are also a point of weakness in conventional reticulation systems, as the manhole sewer connections often crack as the result of ground settlement and traffic impact, with groundwater infiltration then entering the sewer lines.

Infiltration flows dilute the untreated wastewater flow, and result in diminished treatment process performance.

(b) Simplified Sewerage (SS)

Simplified sewerage is also known as shallow sewerage, reflecting the shallower placement of the pipes in contrast to the conventional or deep sewerage. The purpose of simplified sewerage is to reduce the cost of construction and the corresponding cost of operation and maintenance. Simplified sewerage design is based on hydraulic theory in the same manner as for conventional sewerage but has less conservative design assumptions. Smaller diameter pipes are used when water use per person is known to be less and the minimum depth of cover of pipes can be as low as 0.2 m when there is only light traffic. Manholes can be replaced by inspection cleanouts because of the shallow pipes. The design planning horizon can be shorter because the population projection may be uncertain. In a variation of the simplified sewerage, the pipe layout passes through property lots (condominium) rather than on both sides of a street (conventional). Figures 9.6 and 9.7 shows the sewerage layouts in conventional sewerage and in condominium sewerage.

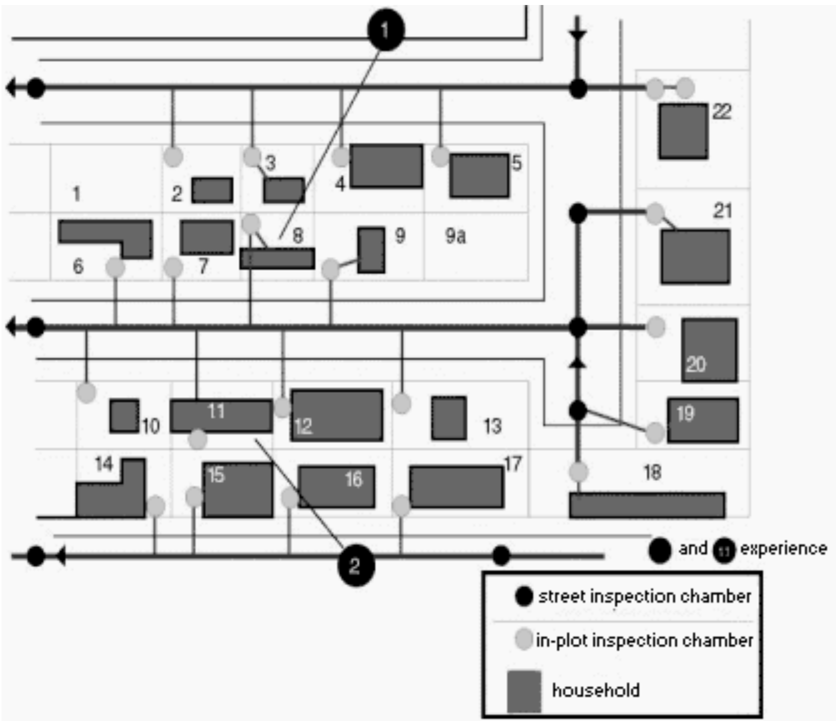

Figure III.9.6 Pipe Layouts for Conventional Sewerage (UNEP)

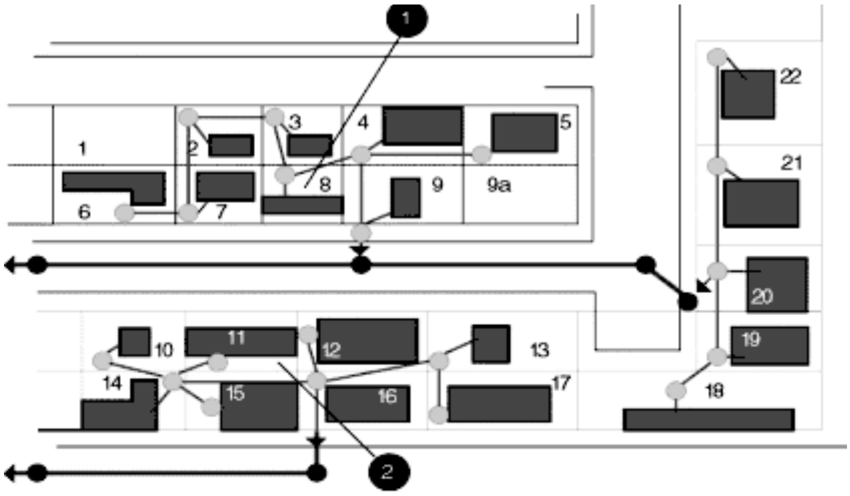

Figure III.9.7 Pipe Layouts for Condominium Sewerage (UNEP)

Minimum line diameters can be reduced from 150 to 100 mm depending on connection numbers, and self-cleansing gradients can be reduced due to smoother pipe material, again producing construction economies. Infiltration opportunities are reduced, thus decreasing the wet-weather flow in the sewer and the hydraulic impact on the treatment plant processes. Back of property collectors are used to minimize sewer length and depth.

Simplified sewerage systems are particularly suitable in high density, low income areas where space is at a premium and on-site solution is inappropriate. The system could also be considered for smaller communities converting from on-site to cluster or central sewerage and treatment. This type of system has already been successfully used for pilot projects in Phnom Penh.

The cost of construction of simplified sewerage can be 30 to 50 % less than conventional sewerage depending on local conditions. Shallow sewerage is also conducive to local community participation because sewer pipes have to cross property boundaries. The community has to agree to this arrangement which extends after construction for maintenance (e.g. unblocking of sewer pipes). The shallow pipe, and hence the shallow trenches, also allow members of the community to participate by, for example, providing labor for digging the trenches. This is in contrast to conventional sewerage where specialized machinery is required for the deep trenches.

(c) Septic Tank Effluent Disposal System (STED)

Settled sewerage refers to sewerage for conveying wastewater that has been settled, for example, in a septic tank. Settled sewerage originated to convey the overflow from septic tanks where the soil cannot cope or absorb the overflow. This usually occurs when the groundwater table is high, or where the soil permeability is low, or where there are rock outcrops. It can also be used when effluent from septic tanks pollutes groundwater and it is necessary to convey the effluent off-site and treat it. Because there are no solids that can potentially sediment in the sewerage pipes, there is no requirement for the self-cleansing velocity. Smaller pipes (75 mm) and lower gradients can be used. The cost of settled sewerage is between a third and a half of conventional sewerage. Originally developed in South Australia to overcome problems with failing septic tanks, it has been used quite widely worldwide to upgrade septic tank systems.

Where there is no existing septic tank, an interceptor box or tank can be used. It functions like a septic tank and designed in the same way (Figure III.9.8). To reduce cost, the wastewater from a group of houses can be connected to one interceptor tank. Just like in a septic tank, the accumulation of sludge has to be removed regularly from an interceptor tank.

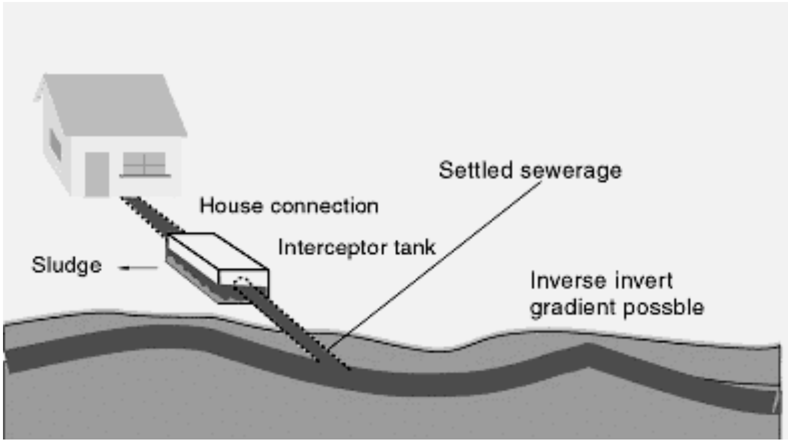

Figure III.9.8 Interceptor Tank in Settled Sewerage (UNEP)

3) Selecting Type of Collection System

The per capita costs of conventional sewerage will be very high because population densities are relatively low therefore septic tanks will remain in service for a large part of the urban area. As population densities increase the discharge of septic tank effluent to soak away pits may no longer be feasible since the risk of contaminating groundwater supplies will increase. Therefore some form of sewerage will be required.

One of the major problems with conventional sewer systems is the level of infiltration that occurs due to groundwater and surface water flows leaking into the sewer system during wet weather. It is almost impossible to eliminate this problem as manholes used for maintenance create points of potential leakage in the sewerage system unless the lids are sealed and bolted to the frame. Leakage is also a problem at pipe joints and the amount can be quite significant when the groundwater level is high.

On the other hand, simplified sewerage systems referred to above enable fully sealed pipes with secure access and inspection points to be constructed so as to eliminate infiltration.

Simplified sewerage appears to be the most technically viable and cost-effective solution for areas in **Zone 1** where septic tanks would be gradually eliminated.

Initially, areas in Zone 2 will not have sewers and will be serviced by on-site septic tanks systems. Sometime in the future, when population densities increase, the effluent from septic tanks in **Zone 2** could be collected by an “Effluent Disposal

System" (STED) and conveyed to the central treatment plant.

Table III.9.15 Proposed Wastewater Collection Method

	2012	2020	Beyond 2020
Zone 1	SS	SS	SS
Zone 2	On-site	STED	STED
Zone 3	On-site	On-site	STED

SS = Simplified Sewerage STED = Septic Tank Effluent Disposal

(4) Wastewater Treatment

1) Septic Tanks

A septic tank is a watertight tank, usually located just below ground, and receives both blackwater and greywater (Figure III.9.9). It can be used with pour flush toilets or cistern flush toilets. It functions as a storage tank for settled solids and floating materials (e.g. oils and grease). The storage time of the wastewater in the tank is usually between 2 and 4 days. About 50% removal of BOD and Suspended Solids (SS) is usually achieved in a properly operated septic tank due to the settling of the solids during wastewater storage.

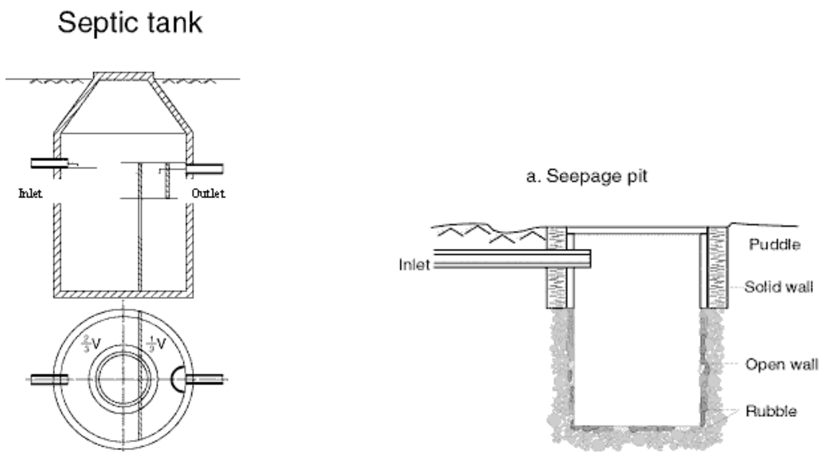

Figure III.9.9 Typical Septic Tank and Leach Pit

A septic tank can be constructed of bricks and mortar and rendered, or of concrete. Its shape can be rectangular or cylindrical. A septic tank can be partitioned into two chambers to reduce flow short-circuiting and improve solids removal. The overflow from a septic tank is directed to a leach pit or trench. A leach pit is similar to the pit of a pit latrine or pour flush latrine. The pit must be sized to allow percolation of the volume of wastewater generated. A pit works well in soils with high permeability.

In soils with lower permeability a trench can provide the larger surface area of percolation (Figure III.9.10). The trench is usually filled with gravel and a distribution pipe for the wastewater is placed in this gravel layer. Soil is then placed above this gravel layer to the ground surface.

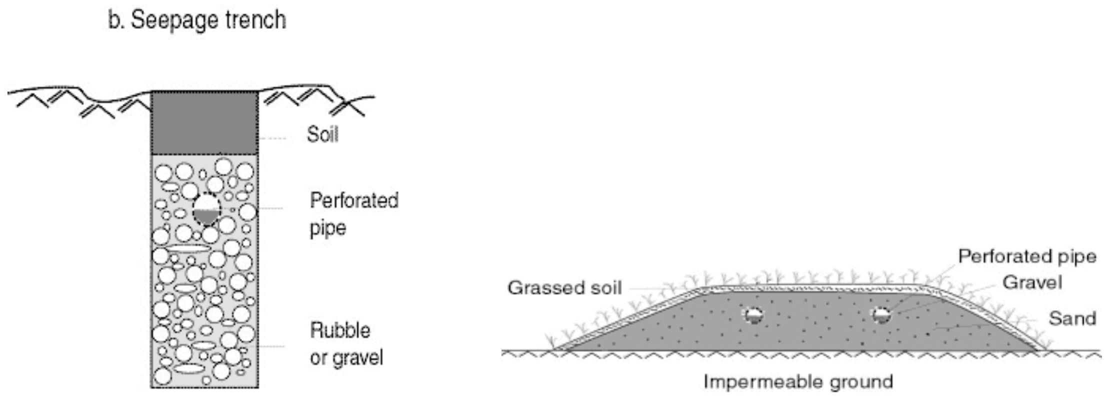

Figure III.9.10 Leach Trench and Evapotranspiration Bed

Leach pit or trench does not work when the soil permeability is too low (e.g. clayey soil or hard rock). In regions where annual evaporation is high, trees and shrubs can be used to help pump the water into the atmosphere by evapo-transpiration. An evapo-transpiration bed can be designed similar to a leach trench, but a suite of suitable local vegetation species tolerant of high nutrients and water are planted above and surrounding the trench. The trench should be sized to store water during the rainy season or low evaporation periods.

A leach pit or drain does not work either when the groundwater table is close to ground surface. In this case off-site disposal is necessary using a settled sewerage system.

The organic solids in a septic tank undergo anaerobic bacterial decomposition just as in the pit of a pit latrine. The sludge needs emptying, and the period between emptying is usually designed to be between 3 to 5 years. The sludge has to be further treated before reuse or disposal.

The septic tank overflow undergoes further bacterial decomposition as it percolates through a leach pit or trench. Soil bacteria, usually under aerobic conditions undertake the decomposition. The BOD of the wastewater can reach a low figure (<20 mg/L) if the distance between the bottom of the pit or trench to the groundwater table is greater than 2 m. Nutrients are not significantly removed by the bacteria and usually pollute the groundwater. Pathogenic bacteria are removed by die-off or filtration by the soil, but viruses may travel further in the soil or groundwater.

Percolation of septic tank overflow is much slower compared to rainwater percolation. This is because a layer of bacterial slime grows on the surfaces of the soil particles, restricting flow. Two leach pits or trenches used alternately, say every 6 months are better than a single leach pit or trench of the same total area for percolation, because as one is used the other will recover its percolation rate.

2) Centralized Wastewater Treatment

Most conventional sewage treatment options are based on approaches to Northern countries' problems, which has usually meant a reduction in biodegradable organic material and suspended solids, plus perhaps some nutrients (nitrogen and phosphorous). Treatment has involved the 'removal' of these pollutants, but removal is usually conversion to another product, usually sludge. Applying the same technologies to developing countries will have three main disadvantages:

- high energy requirements;
- high operation and maintenance requirements, including production of large volumes of sludge (solid waste material);
- they are geared towards environmental protection rather than human health protection - for example, most conventional wastewater treatment works do not significantly reduce the content of pathogenic material in the wastewater

There are some sewage treatment options which are more appropriate to developing country scenarios. Such systems should generally be low-cost, have low operation and maintenance requirements, and, should maximize the utilization of the potential resources (principally, irrigation water and nutrients).

Most of the wastewater generated in Siem Reap flows in open drains to irrigation canals used for rice culture. Very little wastewater is finding its way into the Siem Reap River or Tonle Sap. The main issue is public health and how to control pathogenic material. Any form of sanitation (on or off-site) should have this as its main objective. One of the most viable treatment options which can remove pathogenic material as well as well as organic material is waste-stabilization ponds.

Increasingly, sewage is being seen as a resource. Traditional sewage treatment practices in South-east Asia, for example, seek to use wastes generated through pond systems which are used to cultivate fish and generate feed for animals. The water and nutrient content in wastewater can be very useful for agricultural purposes (for example, through irrigation) if the sewage is treated to a suitable standard.

For Siem Reap low operating cost and low maintenance are the primary criteria for selecting a wastewater treatment system. Three technologies most common in developing countries are compared in Table III.9.16.

- Waste stabilization ponds
- Aerated lagoons
- Extended aeration process using oxidation ditch

Aerated lagoons and extended aeration plants convert organic materials in wastewater to sludge. Both are energy intensive and produce sludge that requires treatment. Extended aeration is more energy intensive but produces less sludge.

Waste stabilization ponds produce sludge when the ponds are cleaned: anaerobic ponds are emptied when 1/3 full approximately at 3 year intervals and facultative ponds at 5 to 8 year intervals.

Table III.9.16 Comparison of Potential Treatment Technologies

	Key Features	Advantages	Disadvantages
Waste Stabilization Ponds (WSP)	• Large surface-area, shallow ponds. • Treatment is essentially by action of sunlight, encouraging algal growth which provides the oxygen requirement for bacteria to oxidize the organic waste.	• Simple to operate • Low operating cost with minimum energy requirement • High level of pathogen removal • Reliable effluent quality because of long retention times	• Requires significant land area • Effluent has a high organic content caused by algae which could be a problem if discharged to a water body i.e. not used for irrigation
Aerated Lagoons	• Like WSPs but deeper and with mechanical aeration. Sedimentation ponds and sludge removal are required downstream of aerated lagoons.	• Less land required than for WSP due to pond depths • Higher organic loading • Simple to operate • Simpler operation and lower cost than oxidation ditch	• Higher energy costs compared to WSP • Mechanical failure of aerators is common • Effluent quality is general not as good as oxidation ditch or WSP • Would require maturation ponds for disinfection prior to agricultural reuse, thereby increasing land requirement
Oxidation Ditch	• Oval shaped aeration lanes with horizontal paddles used to circulate and aerate the wastewater.	• Relatively low sludge production • Reduced land requirement compared to ponds and aerated lagoons.	• Very high energy costs • Complex operation and maintenance • Almost total treatment failure during power cuts • Would require maturation ponds for disinfection prior to agricultural reuse, thereby increasing land requirement

Waste stabilization ponds (WSPs) are selected as the best option for providing good levels of treatment with the lowest possible operating cost. In addition, it is one of the few processes that provide removal of pathogenic material. Ponds also offer a large potential for re-use of the treated effluent into irrigation. The major disadvantage is that the initial capital costs to acquire large areas of land for treatment plant may be quite high.

Should land acquisition and land costs become a constraint for implementation, it will be necessary to consider other treatment options that can substantially reduce land requirements. Aerated lagoons would normally be considered as the next lowest cost option, but the land requirements would still be large.
Oxidation ditch technology appears to be the next most suitable treatment process. It would significantly reduce land requirements, but the energy and maintenance requirements are very high. Furthermore, the effluent would contain a high level of pathogenic material.

Chlorination, which is the most widespread form of wastewater disinfection worldwide, is not suitable for Siem Reap because it has several disadvantages:

- high cost
- complex operation and process control
- hazardous organ chlorine by-products
- low efficiency of virus removal

Therefore, effluent from the oxidation ditch process would require post-treatment in maturation ponds thereby increasing land requirements.

3) Effluent Standards

The Cambodian National Standards for discharges to water courses as produced by Ministry of the Environment are extensive and covering many standards for many pollutants. Standards of primary interest for the sewage treatment plant are as follows:

Table III.9.17 Effluent Standards Affecting Design of Wastewater Treatment Process

Nº	Parameters	Unit	Allowable limits for pollutant substance Discharging to:	
			Protected public water area	**Public water area and sewer**
3	BOD_5 (5 days at 20^0 C)	mg/l	< 30	< 80
4	COD	mg/l	< 50	< 100
5	Total Suspended Solids	mg/l	< 50	< 80
10	Nitrate (NO_3)	mg/l	< 10	< 20
15	Phosphate (PO_4)	mg/l	< 3.0	< 6.0
34	Ammonia (NH_3)	mg/l	< 5.0	< 7.0
35	DO	mg/l	>2.0	>1.0

From sub-decree on water pollution control (council of ministers No. ANRK.BK 06 April 1999), Annex 2

Most of the wastewater will be discharged to irrigation canals upstream of Tonle Sap which is a protected water body. Therefore the treated effluent should meet the stricter criteria. WHO standards for unrestricted irrigation indicate that the effluent should have a faecal coliform count of less than 1000 per 100 ml therefore the effluent will require some form of disinfection.

4) Number of Wastewater Treatment Sites

The physical layout of the centralized collection and treatment system will depend on topography and to a very large extent on the location and number of the treatment plants. The natural gradient in Siem Reap is about 1:1000 with natural drainage flowing from north to south. The collection system must where possible take advantage of this natural gradient and should therefore be arranged from North to South with the treatment plants at the downstream end. The natural gradient is quite low therefore wastewater collection by gravity will only be possible for shorter distances of up to about 2 km to limit the depth of the collection system. Longer distances are technically possible but the cost of the trunk sewers and pumping stations will increase significantly when depth increases beyond 3 to 4 m especially given the high water table. A number of pumping stations will therefore be required to relay wastewater to the treatment site.

a) Layout Options

Two potential treatment plant sites have been identified by other studies that are currently in progress. Both are located south of the city in low lying areas and both offer the potential for discharging treated effluent to irrigation.

To the Southwest the ADB project has identified a 20 ha site. It is located about 1 km from the ring road and is relatively close to the city.

To the Southeast the ADB project has identified a 40 ha site. It is located just south of Cheavs Commune, about 3 km from the ring road and is quite far from the proposed wastewater collection zone.

There are therefore two options for the collection system layout. The first option "***Option 1***" would be to have two separate treatment plants. The city would then be divided into two separate sewerage districts, East and West. Preliminary treatment process calculations indicate that the proposed sites would have sufficient land to use waste stabilization pond, preferred because of their simplicity and low operating cost.

The second option "***Option 2***" would be to convey all the wastewater to a single treatment plant. The city could be divided into two separate sewerage districts but wastewater collected on one side of the Siem River would be pumped over to the other side. The proposed Southeast site (option 2a) would have sufficient land to use waste stabilization ponds. The Southwest site (option 2b) does not have sufficient space for ponds but could accommodate an oxidation ditch process followed by maturation ponds for disinfection.

b) Qualitative Comparison

The options, along with advantages and disadvantages are compared in the following table.

Table III.9.18 Comparison of Wastewater Collection Layouts

Option	Description	Advantages	Disadvantages
Option 1	• Two treatment plants, East and West, using waste stabilization ponds	• Low operating costs for treatment • Less pumping therefore lower operating cost • Shorter travel distance for septage haulers • Reduces the amount of waste concentrated in one place • Easy to implement in phases to match growth, e.g. West before East	• Double the land acquisition process and potential problems • Land acquisition cost is high
Option 2a	• Single treatment plant south-east site, using waste stabilization ponds	• Low operating costs	• Land costs in Cheavs commune may be the highest • Pumping costs will be higher for conveying West District to east side • Increases the amount of waste concentrated in one place and potential environmental impact • Increases travel distance for septage haulers
Option 2b	• Single treatment plant south-west site, using oxidation ditch	• Potentially the lowest land acquisition costs because non-agricultural land use • Lower initial investment	• Oxidation ditch requires enormous amounts of energy therefore very high operating costs • Increases the amount of waste concentrated in one place and potential environmental impact • Increases travel distance for septage haulers • Pumping costs will be higher for conveying East District to west side

c) Life Cycle Cost Comparison

Life cycle costs for the three options are presented in the following table. Land requirements and energy costs for each option are based on preliminary process calculations presented in Table III.9.22.

Unit rates for investment costs and O&M are based on similar projects in other Asian countries. These costs are suitable for comparison of options but should not be used for cost estimating. Land on the East side near Cheavs Commune is expected to be less than land on the West side because it is further away from the urban area. Annual energy costs for the treatment process are estimates on the basis of preliminary process calculations. Energy costs for pumping across the river are included for options with only 1 treatment plant. Mechanical and electrical equipment has an estimated life of 15 years therefore equipment replacement costs are included in the analysis.

Table III.9.19 Life Cycle Cost Comparison

Cost Components	**Option 1** WSP 2 locations	**Option 2a** WSP 1 location East	**Option 2b** OD 1 location West
	East: 6 mld West: 9 mld	15 mld	15 mld
Unit rates			
Typical capital costs (USD/mld)	300,000	300,000	475,000
M&E equipment cost (% of capital total)	2%	2%	20%
Annual maintenance cost (USD/mld)	5,000	5,000	15,000
Capital Cost Component			
Land requirement (Ha) - East	15		15
Land requirement (Ha) - West	20	35	
Land cost	7,500,000	10,500,000	4,500,000
Construction costs	4,500,000	4,500,000	7,125,000
Recurring Cost Component			
Replace M&E every 15 years	67,500	67,500	1,425,000
Annual energy costs (treatment process only)	-	-	610,000
Annual energy costs (incremental pumping only)	-	40,000	20,000
Annual maintenance costs	75,000	75,000	225,000
Present value of recurring cost	1,185,402	1,800,301	13,828,895
Life cycle cost including land	**13,185,402**	**16,800,301**	**25,453,895**

Assumes a 5% discount rate Land cost: $10/m2 rural (East site) $30/m2 peri-urban (West site)

Selecting the preferred option comes down to a trade off between initial investment costs and annual operating costs. The use of WSP in option 1 and 2a significantly increases the cost of land acquisition but this is compensated by the lower construction costs and significantly lower operating costs.

The use of oxidation ditch in option 2b reduces the land acquisition cost but significantly increases the annual operating costs.

Option 1 is selected as the preferred option because it is the most cost-effective solution and is most likely to be sustainable in the long term. It is also makes it easier to implement because the projects are smaller and can be implemented at different times to match different growth patterns in East and West districts.

9.2.6 Sewerage Infrastructure Requirements

(1) Planning Framework

1) Planning Horizon and Design Capacities

The study has adopted a planning horizon of 2020. In industrialized countries it is common to design treatment facilities pumping stations and rising mains upon the demand of the next 10 to 20 years. Trunk sewers have a much longer service life and are normally designed for a 50 year life. However it is important to consider the relatively dynamic and unpredictable nature of growth in the Siem Reap district.

Therefore it is more prudent to design system capacity of the first phase of a project for a rather shorter period of 2012. Periodical extensions of pumping station and treatment capacity should then follow, always adapted to the observed increase of demand and considering experience gained through operation of the first phase facilities. Capacity of trunk sewers should be based on flows for 2020 because these cannot be upgraded. Longer design planning horizons are not recommended since self-cleansing velocities would probably not be achieved potentially contributing to the failure of the system.

2) Target Areas and Wastewater Management System

As discussed in "Options for Wastewater Servicing" the urban area has been divided into 3 zones for the purposes of planning wastewater management. The main parameter used to define the zones is population density for 2020. Furthermore Zone 1 corresponds to the area serviced by the newly constructed water supply system where the amount of wastewater is expected to increase significantly.

Table III.9.20 Wastewater Management Servicing by Zone

Zone	Characteristic	Wastewater Management System		
		2012	2020	Beyond 2020
1	Medium to high density urban core, serviced by piped water supply system	SS at the community level with conventional trunk sewers and centralized treatment		
2	Medium density urban	Septic tanks	Upgrade to STED	Upgrade to SS
3	Low density urban	Septic tanks	Septic tanks	Upgrade to STED

SS: simplified sewerage STED: Septic Tank Effluent Disposal System

The proposed wastewater management area is divided into East and West districts separated by the Siem Reap River.

3) Populations

Future population projections, domestic and tourism are an integral component of planning for future wastewater infrastructure. These projections have been developed by the JICA study team for each village. Using GIS tools, the projected populations are distributed into each proposed service area and sewerage district on the basis of contributing area. The tourist population indicated in the following table is a monthly total for the peak month of December.

Table III.9.21 Populations in Wastewater Management Area

Population by Zone	2004		2012		2020	
	Domestic	Tourism	Domestic	Tourism	Domestic	Tourism
Zone 1	26,985	5,690	31,511	15,225	35,718	18,056
Zone 2	21,247	2,077	26,787	5,458	37,804	6,553
Zone 3	20,292	540	24,997	1,681	38,672	2,081
Total	68,524	8,307	83,295	22,364	112,194	26,689

Population East District	2004		2012		2020	
	Domestic	Tourism	Domestic	Tourism	Domestic	Tourism
E1	12,905	1,603	16,296	5,124	18,682	6,219
E2	5,678	575	11,218	1,707	15,386	2,120
E3	7,110	28	11,815	187	16,002	273
Total	25,693	2,206	39,329	7,018	50,070	8,612

Population West District	2004		2012		2020	
	Domestic	Tourism	Domestic	Tourism	Domestic	Tourism
W1	14,080	4,087	15,215	10,101	17,036	11,837
W2	15,569	1,502	18,018	3,751	22,418	4,433
W3	13,182	512	18,048	1,495	22,670	1,807
Total	42,831	6,101	51,281	15,346	62,124	18,077

4) Water Supply

Water demand projections for local domestic and tourism have been developed by the JICA study team for each village. Using GIS tools, the projected water demands are distributed into each proposed service area and sewerage district pro rated on the basis of contributing area. The water demand for tourism indicated in the following table is the daily average during the peak month tourism month of December.

Table III.9.22 Water Demand by Wastewater Management District

Water Demand m3/day	2004		2012		2020	
	Domestic /Other	Tourism	Domestic /Other	Tourism	Domestic /Other	Tourism
East	3,213	499	5,522	1,740	8,287	2,550
West	5,542	2,158	9,004	5,095	12,866	6,383
Total	8,755	2,657	14,527	6,835	21,152	8,933
Average litre per capita	129	320	174	307	189	335

5) Wastewater Generation

Wastewater production is a function of the water that is consumed however not all water is returned as wastewater. Some portion will be consumed for drinking and cooking or may be used for watering gardens or washing cars. The wastewater return factor generally ranges between 0.70 and 0.85. Higher return factors are typical for low to middle income households or high density urban areas whereas lower return factors are typical for high income households or lower density sub-urban areas with larger plots.

The following return factors have been adopted for planning wastewater quantities:

- Domestic : 0.85
- Hotels/Guesthouses : 0.70
- Public/Institutional : 0.80

Table III.9.23 Wastewater Generation

Wastewater Production m3/day	**2004**		**2012**		**2020**	
	Domestic /Other	Tourism	Domestic /Other	Tourism	Domestic /Other	Tourism
East	2,686	354	4,617	1,223	5,106	1,721
West	4,620	1,524	5,905	3,635	10,613	4,537
Total	7,306	1,879	10,522	4,859	15,719	6,258
Average litres per capita	108	226	126	218	141	234

Wastewater m3/day	**2004**		**2012**		**2020**	
	Domestic /Other	Tourism	Domestic /Other	Tourism	Domestic /Other	Tourism
E1	1,423	227	2,163	882	3,147	1,277
E2	597	85	1,285	300	1,959	444
E3	665	42	1,170	42	1,818	73
Sub-total	2,686	354	4,617	1,223	6,924	1,794
Total	3040		5841		8718	

Table III.9.23 Wastewater Generation (Cont'd)

Wastewater m3/day	2004		2012		2020	
	Domestic /Other	Tourism	Domestic /Other	Tourism	Domestic /Other	Tourism
W1	1,476	757	1,738	2,165	2,336	2,883
W2	1,633	270	2,248	918	3,220	1,102
W3	1,511	498	1,918	553	5,058	553
Sub-total	4,620	1,524	5,905	3,635	10,613	4,537
Total	6145		9540		15150	

6) Wastewater Collected and Treated

As discussed under servicing options, the centralized wastewater collection and treatment system will initially only service areas within Zone 1. After 2012 when population densities increase the collection system will be extended into Zone 2. Therefore the trunk facilities (collector sewers and pump stations) should have sufficient capacity to accommodate peak flows from both zones.

Similarly the capacity treatment plant should also be based on flows received from both zones 1 and 2 with the first stage designed to meet peak flows from Zone 1.

(a) Connection Ratio

The amount of wastewater actually collected and conveyed to the treatment plant will depend on how many households and hotels/guesthouses connect to the sewer system. This will be a function of branch sewer system coverage as well as the costs to connect. It will also be a function of whether or not there are local by-laws to enforce mandatory connection.

A factor called "connection ratio" is used to reflect the fact that some households or hotels/guesthouses in sewer served areas will not be connected to the system

The following connection ratios have been adopted for planning:

Table III.9.24 Connection Ratios

Zone 1	**2012**	**2020**
Domestic	50%	80%
Hotels/guesthouses	75%	100%
Public/Institutional	75%	100%
Zone 2	**2012**	**2020**
Domestic	0%	60%
Hotels/guesthouses	0%	75%
Public/Institutional	0%	75%

(b) Infiltration Factor

Calculations for the amount of sewage collected must also include a factor for the groundwater and surface water that enters the system at pipe joints and manholes. A factor of 15% has been added to the total projected flow. The factor reflects relatively high groundwater tables and poor surface drainage.

(c) Wastewater Collected

Wastewater collected is equal to: (Water consumed) x (connected ratio) + (Infiltration)

It is assumed that water demand will be met, in other words, demand is equal to consumption. The total flow (including infiltration) that would be conveyed to treatment is as follows:

Table III.9.25 Wastewater Collected and Conveyed to Treatment

Average flow during peak month m3/day	2012		2020	
	East	West	East	West
By district	2,016	2,879	6,119	8,658
Total	4,896		14,777	

Detailed calculation of wastewater amounts by village is in Table 1 (Appendix).

7) Wastewater BOD Loading

Wastewater composition differs from one situation to the other and is dependant on the level of sanitation, water usage, type of collection system, retention time in sewers and infiltration. Wastewater characteristics will influence the choice of treatment method, extent of treatment and quantities of solids produced.

Average Biological Oxygen Demand (BOD) is one two most important factors that determines the design and performance of waste stabilization ponds. The other is hydraulic flow rate.

Wastewater strength (BOD) is estimated by assuming an organic loading of 40 grams/person/day which is a typical value for domestic wastewater in South/East Asian countries.

Table III.9.26 Wastewater BOD Characteristics

Wastewater characteristic	2012		2020	
	Domestic /Other	Tourism	Domestic /Other	Tourism
Wastewater average litre/capita	126	218	141	234
grams BOD per capita per day	40	40	40	40
BOD at source (mg/l)	317	184	284	171

The BOD values indicated in the previous table will be diluted by infiltration of groundwater into the collection system.

(2) Infrastructure Capacities and Staging

A preliminary estimate of the trunk sewer and treatment plant capacities has been carried out in order to provide a basis for planning the phasing of priority projects and determining the land requirements at treatment plants. Preliminary design criteria should be re-evaluated during subsequent feasibility studies and detail design stages. The proposed wastewater collection system layout and location of treatment plants is presented in Figure 8 (Appendix).

1) Service Area and Population Served by Sewerage System

Table III.9.27 Sewer Service Area and Population

	2012 Zone 1	**2020** Zone 1 & 2
Area - East	296	562
Area - West	288	705
Total area	584	1,267
Domestic population	31,511	73,522
Tourist population	15,225	24,609
Total population served	46,736	98,131

2) Trunk Sewers

Criteria used for the evaluation and preliminary sizing of trunk sewers are as follows:

Peak factor for trunk sewers — 2.5 for population < 50,000

Hydraulic design of gravity pipe:

- Manning's equation — $V = 1/n \, R^{2/3} S^{1/2}$,
- Roughness factor — n= 0.013 uPVC pipe
- Minimum velocity — 0.60 m/s initial flow; 0.80 m/s ultimate flow
- Maximum velocity — 3.00 m/s
- Maximum depth — d/D= 0.8 at ultimate peak flow
- Minimum pipe size:
- Collector sewers: — 250 mm
- Trunk sewers — 300 mm

The trunk sewers represent the backbone of the system and have been sized for stage 2 flows in 2020. A number of smaller collector and lateral sewers can be configured to collect wastewater from households and convey it to the trunk sewers shown.

Ground elevations are taken from topographic maps prepared for the study and should be confirmed by survey at a subsequent feasibility study stage. The invert depth of trunk sewers at the upstream end of the sewerage catchments has been taken as 1.0m to allow for the connection of lateral sewers. Depth and pipe slopes have been selected to minimize installation cost and to achieve self cleansing velocities under peak flow conditions.

Preliminary configuration of the collection system for the East and West drainage districts is presented in Figures 9 and 10 (Appendix). Total quantities of trunk and collector sewer are estimated on the basis of the preliminary layouts as follows:

Table III.9.28 Length of Trunk Sewers

Trunk sewers Diameter (mm)	East	West
	Length (m)	Length (m)
300	9860	3615
400	1290	3600
600	2270	2140

3) Branch Sewers

In Zone 1 the local collection systems will follow design practices for modified conventional sewerage (simplified sewerage). In general pipes will not be routed in-road. Rather, pipes will be routed in private or semi-private space, through either back or front yards or small back lanes between buildings. Simplified sewers will be laid at shallow depths, often with covers of 400mm or less. The minimum allowable diameter is 100mm rather than the 150mm or more that is required for conventional sewerage. The relatively shallow depth allows small access chambers to be used rather than large expensive manholes.

In zone 2 the local collection system will be comprised of shallow pipes following design criteria for effluent drainage systems. The minimum pipe diameter can be reduced to 75mm.

The quantity of small diameter branch sewers and is estimated very roughly by using typical average length of 350m per hectare. Domestic connections are assumed to be 20 m per household.

Table III.9.29 Length of Branch Sewers

Length of branch sewers (km)	2012	2020
East	104	198
West	101	257

4) Pumping Stations

The capacity of pumping stations is based on the following criteria:

Peak factor: 2.5

Number of pumps: 50% standby capacity at peak hour
100% standby capacity at non-peak

Hydraulic design for pressure pipe:

- Hazen Williams: $V = 0.85\ C\ R^{0.63}\ S^{0.54}$
- Roughness factor: C= 100 ductile iron pipe
- Minimum velocity: 0.8 m/s
- Maximum velocity: 3.0 m/s

Design discharge at pumping stations is based on average wastewater flows (including infiltration) and a peaking factor for diurnal flow variation. The installed pump capacity should include sufficient spare capacity (in the form of additional pump units) to allow for equipment breakdown and lengthy repair periods. A minimum standby capacity of 50% at peak flow is recommended.

Table III.9.30 Pumping Station Design Discharges

Pump stations	Design Discharge (litre/sec)					
	2012			**2020**		
	Installed 1.5x peak	peak	average	Installed 1.5x peak	peak	average
PS-E1	86	57	23	266	177	71
PS-E2	33	22	9	127	85	34
PS-E3	47	31	13	101	67	27
PS-E4	53	35	14	121	81	32
PS-W1	123	82	33	361	241	96
PS-W2	92	62	25	203	135	54
PS-W3	53	35	14	104	70	28
PS-W4	-	-	-	68	45	18
PS-W5	-	-	-	13	9	4

PS = pump station

The main pumping stations PS-E1 and PS-W1 will convey wastewater in pressure mains directly to screening and grit removal facilities at the head of the treatment plant. This will eliminate the need to have another pumping station at the treatment plant.

There is a large difference in flows between stage 1 and stage 2 at the main pumping stations. This creates a problem when sizing rising mains since the velocities will be too low initially if the pipe is sized for the ultimate flow. It is therefore necessary to install twin 300mm diameter rising mains. The first pipe would be installed for stage 1 and a second pipe of equal diameter installed at stage 2.

5) Waste Stabilization Ponds

The capacity of treatments plants is based on meeting process requirements for the year 2020 with a first phase sized for 2012. Graphical summaries depicting the calculation of wastewater flows for the East and West district for the years 2012 and 2020 are presented in Figures 11 and 12 (Appendix).

Average dry weather design flows (including infiltration) for the peak tourism month of December are as follows:

Table III.9.31 Treatment Plant Capacity

Hydraulic capacity m3/day	East		West	
	2012	2020	2012	2020
Zone 1	2,016	4,378	2,879	5,475
Zone 2	-	1,741	-	3,183
Total	2,016	6,119	2,879	8,658

Graphical summaries depicting the calculation of BOD loadings for the East and West district for the years 2012 and 2020 are presented in Figures 13 and 14 (Appendix). A BOD removal efficiency of 40% has been adopted for septic tanks.

By 2020 the effluent from septic tanks in Zone 2 will be collected by an "Effluent Drainage System" connected to the trunk sewer system. Septic tanks will provide primary treatment therefore septic tank effluent will have a lower BOD strength and will dilute the influent BOD at the treatment plant.

Table III.9.32 Organic Loading at Treatment Plants

Organic BOD loading	East		West	
	2012	2020	2012	2020
(mg/litre)	232	198	201	171
(kg/day)	468	1172	578	1442

Preliminary process calculations are presented in section 5. Calculations for stabilization ponds are based on equations and design notes published by D.D. Mara et al. and Marais. These are widely recognized and used extensively in the design of ponds in countries with tropical climates. Design influent BOD for design calculations is 300 mg/l. It is higher than the calculated BOD to allow for the treatment of medium strength septage. Both treatment plants will have the following ultimate configuration:

Table III.9.33 Staging and Physical Arrangement of Ponds

WSP process	Arrangement Phase I - 2012	Arrangement Phase II - 2020	Retention time Phase II - 2020	Depth
Anaerobic ponds	2 In parallel	4 In parallel	1 day	4 m
Facultative ponds	2 In parallel	4 In parallel	4.4 days	1.5 m
Maturation ponds	2 in series	2 in series	4 days each	1.5 m

The treatment process will produce a very high quality effluent with filtered BOD less than 30 mg/l and faecal coliform counts below the recommended 1000 per 100 ml suitable for unrestricted irrigation.

The treatment process would include a head works with the following:

- Influent screening and grit removal
- Flow measurement
- Flow splitting and distribution to anaerobic ponds

Half the process train would be implemented for Phase I even though the flows at 2012 are only 1/3 of the 2020 flows. This will provide reserve capacity for growth beyond 2012 and allow some flexibility in timing the expansion to phase 2. Land requirements based on process calculations are identified as follows:

Table III.9.34 Land Requirements for WSP

Land requirements m^2	East 2020	West 2020
Anaerobic ponds	12,592	15,745
Facultative ponds	64,333	89,110
Maturation ponds	33,810	47,680
30% allowance for civil works and sludge drying beds	33,220	45,760
Total	143,955 say 15 ha	198,295 say 20 ha

9.2.7 Septage Management

(1) Concept

This study proposes a concept for wastewater management in order to cope with the coming challenges connected to the rapid growth in Siem Reap. Part of the concept includes the use of septic tanks in low density urban areas where the installation of piped sewerage would not be cost effective.

The basic components for improved septage management are an increased rate of septage collection, the treatment of all collected septage at the wastewater treatment plant and the reuse of treated sludge in agriculture.

The present collection capacity is non-existent and has to be created to meet the coming demand for septic tank emptying, because the number of septic tanks in Siem Reap is increasing rapidly. Additional efforts have to be spent on shortening the emptying intervals of septic tanks. This will improve solids retention in septic tanks and prevent increased solids accumulation in the drainage system. The translation into action of these suggestions requires substantial improvements of the management capacity in the concerned public sector utility.

The collected septage will be dewatered and treated at the site of the proposed wastewater stabilization ponds. This treatment will separate the sludge in two fractions. The liquid fraction will be discharged at the head of the wastewater treatment process for further treatment. The solids fraction will be applied to sludge drying beds and then stored for a period of time until it can safely be reused in agriculture.

Reuse of the produced solids instead of disposal on the landfill is recommended, because it can generate revenues, it saves landfill space and it supplies Siem Reaps' agriculture with valuable soil-conditioner.

(2) Septage Characteristics

Characteristics of faecal sludge and wastewater differ widely as shown in Table III.9.35. Septage is a term used to describe the contents of septic tanks which usually comprise settled and floating solids as well as the liquid portion.

Table III.9.35 Septage Characteristics

Item	**Type A (High-strength)**	**Type B (Low-strength)**	**Sewerage (For comparison)**
Example	Public toilet or latrine	Septage	Tropical sewage
Characterization	Highly concentrated Mostly fresh FS stored for days or weeks only	FS of low concentration usually stored for several years; more stable than Type A	
COD mg/l	20,000 to 50,000	< 15,000	500 to 2,500
COD/BOD	5:1 to 10:1	5:1 to 10:1	2:1
NH4-N mg/l	2,000 to 5,000	<1000	30 to 70
TS mg/l	> 3.5%	< 3%	< 1%
SS mg/l	> 30,000	Approx. 7,000	200 to 700
Helminth Eggs no./liter	20,000 to 60,000	Approx. 4,000	300 to 2,000

SANDEC, from Accra/Ghana, Manila/Philippines and Bangkok/Thailand.

The characteristics of municipal wastewater typical in tropical countries are also included for comparison. Organic and solids contents, ammonium and helminth egg concentrations measured in FS are normally higher by a factor of 10 or more than in wastewater. Moreover, FS differs from wastewater because its quality can vary very much. Storage duration, temperature, intrusion of groundwater in septic tanks, performance of septic tanks, and tank emptying technology and pattern are parameters which influence the sludge quality and are therefore responsible for its high variability.

(3) Septage Collection

Septic tanks in Zone 1 will eventually be phased out when households are connected to the sewer system. Septic tanks in Zone 2 and 3 will remain in service until beyond 2020. The number of septic tanks needing regular cleaning will therefore be significant and there will be an obvious need to implement an effective management system.

The quantities of septage must be estimated in order to plan for the collection and treatment infrastructure. The actual quantities are difficult to predict since many factors are unknown:

- Size of tanks
- Required cleaning frequency
- Number of hotels, guesthouses, restaurants and commercial businesses

The key assumption is that septic tanks should be emptied at approximately 3 year intervals or when they get full. Obviously tanks serving large hotels will need to be emptied more frequently but these represent a smaller portion of the total load and can easily be accommodated by the number of trucks planned for the average condition. Septage quantities are estimated on the basis of 1 litre/person/day which the typical volumetric rate quoted in literature (SANDEC) for nominal cleaning intervals of 3 years. Number of persons using septic tanks includes number of tourists and is based on planned sewer connection ratios for each WM zone. It is assumed that all households and hotels that are not connected to a sewer will use septic tanks.

Estimated septage quantities are as follows:

Table III.9.36 Estimated Septage Quantities

Service details	East		West	
	2012	2020	2012	2020
Population with septic tanks	34,356	37,518	49,269	54,307
Septage production(1) (litre/day)	34,356	37,518	49,269	54,307
No. of trucks per day (2)	8	8	11	12
Required number of trucks	4	4	5	6

(1) Assumes 1 litre per person per day for a 3 year cycle
(2) Assumes a 3000 litre vacuum tanker, 6 days a week
(3) Assumes each truck operates 3 loads per day, and spare capacity for vehicle maintenance

(4) Overview and Selection of Treatment Options

In Siem Reap there is no formally organized septage collection service and no disposal site. The current widespread practice is for privately owned vacuum tankers to discharge their load the shortest distance possible from the points of collection to render collection services and earned income more effective. Septage is sometimes disposed of and re-used in agriculture untreated in the majority of cases, creating enormous health risks and water pollution.

The various options for septage treatment are illustrated in the following figure.

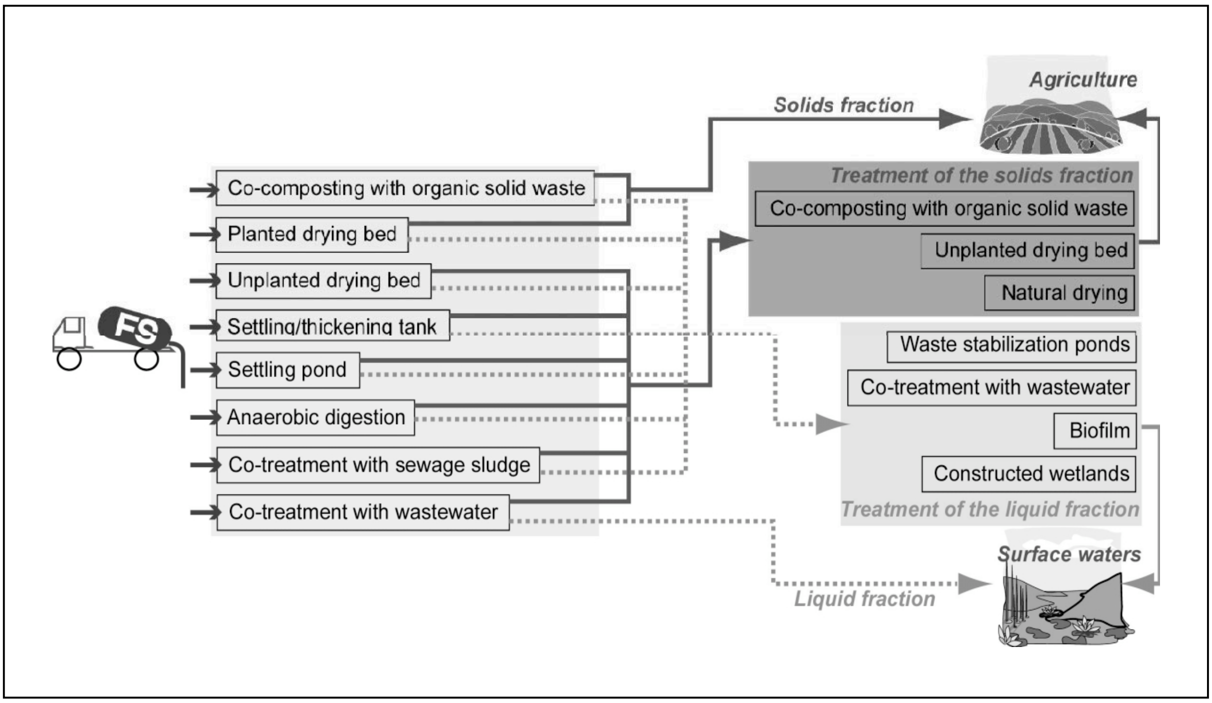

Figure III.9.11 Septage Treatment Options

A basic principle of fecal sludge treatment consists in separating solids and liquids through sedimentation and thickening in ponds or tanks or filtration and drying in drying beds. Resulting from this is a solid fraction of variable consistency, which may be designated as "Biosolids", and a liquid fraction. The solids fraction may require a post treatment to meet the requirements for reuse in agriculture as soil-conditioner and fertilizer, or for disposal in a landfill. A polishing treatment may be necessary for the liquid fraction before safe discharge in surface waters.

Co-composting with organic solid waste is a natural process allowing the sludge to become more hygienic in a relatively short time. This is due to high temperatures of 50 to 70°C, which are reached during the thermophilic degradation process.

The optimal water content for the composting process is 50 to 60 %. If the water content is higher, the aerobic degradation process is hampered. The characteristics of Siem Reap solid waste is not know but studies in Phnom Penh indicate that the organic portion of the municipal solid waste has water content close to 60 %. It is likely the same in Siem Reap therefore composting would not be feasible.

Co-composting of pretreated and thickened septage with organic solid waste might be possible however this can only be considered if the organic material can be separated from the solid waste stream. It would also create a number of operational problems at the disposal site.

Co-treatment with wastewater appears to be the most practical option if the proposed wastewater treatment plants are constructed.

The concentration of suspended solids in septage is 10 to 100 times higher than in domestic wastewater. Discharging septage directly into the waste stabilization pond would lead to total failure of the wastewater treatment system. Therefore septage would have to be separated into solid and liquid fractions. The liquid fraction of the septage would enter the wastewater stream and be treated in the waste stabilization ponds. The solids fraction of the septage will be applied to sludge drying beds and matured for 90 days until is hygienically safe for use in agriculture.

(5) Solids-Liquids Separation

Technologies for solids-liquids separation such as gravity sludge thickeners, centrifuges, filtration or other methods requiring electrically driven mechanical equipment are not appropriate because they are too expensive and complex to be operated and maintained. Irregular power supply, poor daily maintenance and lack of spare parts are likely to render these installations inoperative within a few months after commissioning.

Sedimentation/thickening tanks offer the most suitable option for solids-liquids separation. Other low cost options that might be feasible include sedimentation in primary ponds and sludge drying beds. These other options are compared to sedimentation tanks in the following paragraphs. Sedimentation/thickening tanks are selected as the preferred method of solids-liquid separation because they will require the least amount of land and will be the least problematic in terms of operation and maintenance.

1) Sedimentation/Thickening Tanks and Primary Ponds

Similar to wastewater stabilization ponds, separation and partial stabilization of the solids in a deeper anaerobic primary pond is also possible for septage. However, the size of the solids storage volume must be much larger or the pond sludge removed more frequently compared to anaerobic ponds treating wastewater.
The question is whether it will be more practical to use a sedimentation/thickening tank for solids separation and, thereby, limiting the de-sludging periods to a few weeks, or to de-sludge a pond every 0.5-2 years.

Table III.9.37 Comparison of Sedimentation/Thickening Tanks vs. Primary Ponds

Parameter	**Primary Anaerobic Pond as Sedimentation Unit**	**Sedimentation/ Thickening Tank**
Construction	Very simple; only limited additional costs	More costly but simple in construction
Daily Operation	No mechanical equipment required	No mechanical equipment required
Sludge Removal	Every 0.5-2 years; very large sludge volumes	Every few weeks; small sludge volumes
Potential Problems	Handling of huge sludge volumes; area for subsequent treatment must be larger (e.g. composting, storage, drying); since operation / maintenance is very irregular it tends to be neglected	Organisation of regular de-sludging operation demands a reliable institutional management structure at municipal level to support adequate operation and maintenance.

2) Sedimentation/Thickening Tanks and Sludge Drying Beds

Sedimentation/thickening tanks require a much smaller per-capita area than sludge drying beds, as the process of separating settable solids requires relatively short hydraulic retention. The space required to store the separated solids bears little on the area requirement.

In contrast to this, dewatering and drying of thin layers of sludge on sludge drying beds calls for comparatively long retention periods.

Approximate land requirements for settling/thickening tanks and for sludge drying beds can be estimated, based on experience in other developing countries and the results of studies reported by SANDEC. The following table provides an estimate of plant size in terms of square meters required per capita.

Table III.9.38 Comparison of Land Requirements for Sludge Treatment

	Attainable TS %	Assumed Loading cycle	TS loading kg TS/m2·yr	Required Area m2/cap(1)
Sedimentation/ Thickening Tank	14	8-week cycle (4 weeks loading + 4 weeks consolidating; 6 cycles annually); two parallel settling tanks	1200	0.006
Sludge Drying Bed	70	10-day cycle (loading-drying removing; 36 cycles annually)	100-200	0.05

(1) Assumed parameters: Septage quantity = 1 litre/cap·day; TS of the untreated FS = 20 g/l

(6) Proposed Septage Treatment Facility

Septage will be co-treated with wastewater at each of the two proposed waste stabilization pond sites.

The following schematic shows the typical arrangement for co-treating low to medium strength septage with wastewater. It comprises pre-treatment units (two sedimentation tanks in parallel) for solids-liquids separation followed by co-treatment with domestic wastewater in a series of anaerobic, facultative and maturation ponds. The septage should first be pre-conditioned to remove gross solids and inorganic materials. This can be achieved by separate screening and grit removal.

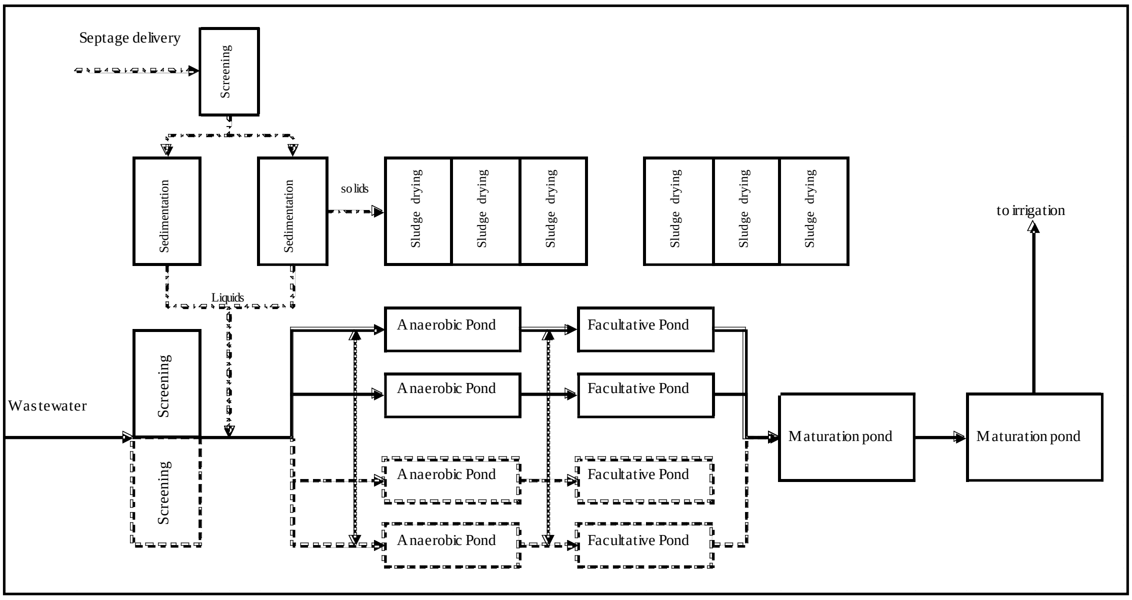

Figure III.9.12 Schematic of Wastewater and Septage Treatment Facility

The twin sedimentation tanks are batch operated and loaded by vacuum trucks at the deep end of the tank to improve solids separation. The tanks are sized to be filled within 30 days and work from then on as sludge accumulator similarly to a septic tank. Sludge loading is then transferred to a parallel tank. The settled sludge is stored and the supernatant flows from the tank into the anaerobic ponds. The operating cycle lasts eight weeks. The settled and thickened sludge is removed at the latest point in time when the tank is due for a new operating cycle. Consolidation periods thus last about one month. The tanks, which are accessed by a ramp, are emptied by front-end-loaders.

The thickened, dewatered or partially dried sludge (“process sludge”), obtained after solids separation by sedimentation requires further treatment. The treatment objectives are dependent on the final use of the process sludge, viz. in horticulture, agriculture or land filling.

Dewatering or partial sun drying of the solids from sedimentation or primary pond units will be required where the process sludge is to be transported as a spadable product. This will also significantly reduce transport volumes (sludge volumes are halved if the water content is reduced for example from 90 to 80 %).
The dewatering/drying period is dependent on climatic conditions and may range from days to weeks to obtain a spadable product for disposal or months to obtain a hygienically safe product that can be used for agriculture.

Process sludge produced by sedimentation and scum formation in settling/thickening tanks or in primary anaerobic ponds can be dried using one or a combination of two methods:

- Dewatering/drying on sludge drying beds
- Dewatering/sun-drying on open land within the WSP site

It is assumed that solids will be re-used in agriculture therefore land requirements for the proposed treatment plant will be based on using sludge drying beds sized to provide 90 days of storage. The drying beds can be kept dry during the rainy season by providing a simple roofed superstructure.

The quantity of sludge produced by the septage is calculated on the basis of the following typical parameters:

- Volumetric septage loading : 1 litre/person/day
- Solids loading : 18 grams/litre
- Organic loading of liquid portion : 1500 mg/litre
- Sludge drying bed thickness : 200 mm

Table III.9.39 Solid and Organic Loading Produced by Septage Treatment at WSP

Parameter	East		West	
	2012	2020	2012	2020
Organic BOD loading to anaerobic pond (kg/day)	52	56	74	81
Settled sludge volume (m3/sedimentation tank)	133	145	190	210
Area of sludge drying beds (m2)	1,992	2,176	2,857	3,149

The organic loading to the anaerobic ponds is relatively small and will not overload the wastewater treatment process.

9.3 Projects and Programs

9.3.1 Objectives and Step-wise Interventions

The primary objectives of proposed sewerage and drainage interventions are identified in order of priority as follows:

- Improve health and sanitation
- Improve healthiness and urban hygiene at the neighbourhood level
- Prevent environmental degradation and improve water quality in Siem Reap river

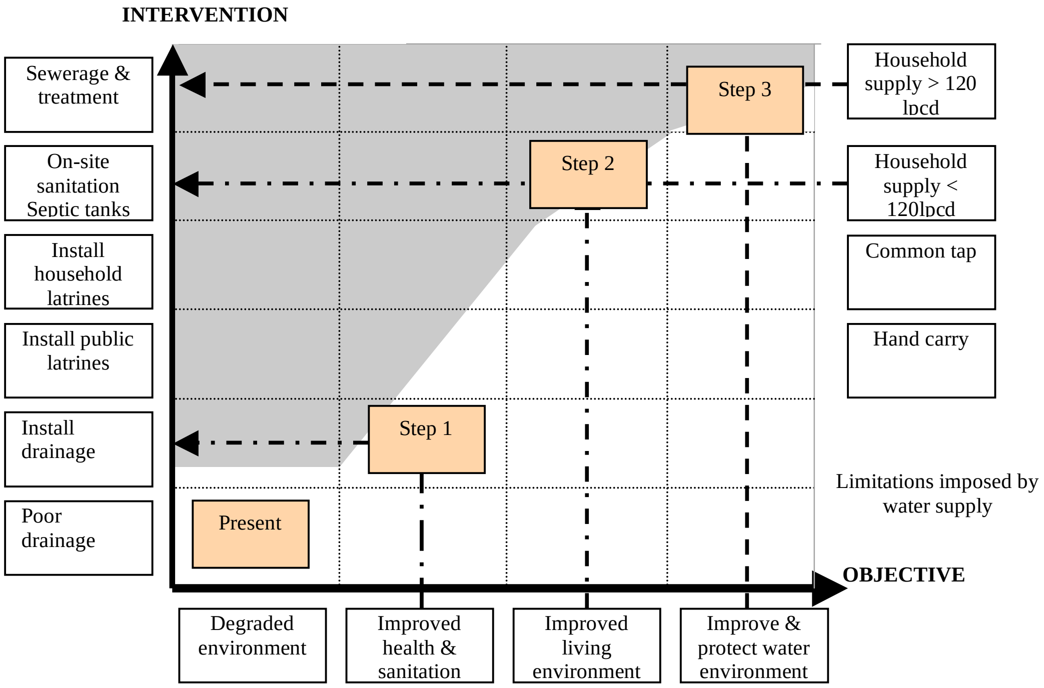

Figure 9.13 Objectives/Intervention Matrix

(1) Step 1

The first step is to improve health and sanitation. This can be achieved by improving stormwater management and the drainage system. Improved drainage will remove stagnant pools of wastewater away from dwellings and reduce flooding incidence and the resulting overflow of wastewater onto streets and into public areas.

(2) Step 2

The second step is to improve the living environment. In low density urban areas (zone 2 and 3) this can be achieved by ensuring that septic tanks are properly installed and maintained at every household and tourist hotel/guesthouse. This would include developing the capacity to manage regular cleaning of septic tanks and the construction of treatment facilities for disposal of septage. In high density central core the objective can only be met by providing a sewerage system.

(3) Step 3

The third step is to protect water quality and prevent environmental degradation. This can only be achieved by the implementation of a centralized sewerage system Sewerage systems will not be feasible in low density urban areas (zone 3) or areas where water supply is not well developed. The sewerage system installed in zone 1 can be gradually extended to serve zone 2 by the use of small bore sewers connected to the conventional sewerage network.

Many drainage and sewerage projects in other countries have failed because local capacity for operation and maintenance was lacking. Experience in many developed and developing countries has shown that when implementing large scale infrastructure it is better to proceed in a systematic way by taking several small steps instead of one big leap.

Smaller projects implemented in series provide a chance to build local management capacity and achieve success before moving on to the next step. Smaller projects offer a number of other advantages:

- easier to fund
- faster and easier to implement and see results
- easier to make adjustments; lessons learned from one project can be applied to the next
- reduces the burden on local financial resources for O&M, allows more time to implement fees and develop O&M budgets
- allows more time to gradually build up staffing levels
- provides more time to learn the skills required for management, O&M of facilities and to adjust to the steep learning curve.

Each project should include a technical assistance component for building O&M management capacity.

9.3.2 Proposed Projects and Programs

The list of proposed projects is presented in Table III.9.40. The projects are listed in order of priority for step-wise development of sewerage and drainage infrastructure. Project briefs are presented in Tables 6 (appendix)

Table III.9.40 Project Identification

Proj. ID	Title	Description	Implementing Agency	Schedule
SD-1	Drainage & Sewerage West District Zone 1	Improve drainage. Rehabilitate town center drain, install interceptor sewer, main pump station and wastewater treatment plant. Includes institutional/ organization/ management study. Does not include sewer reticulation. *Detailed design by ADB in progress. Current funding commitment of US$4.5 to be increased.*	MPWT/ DPWT	2005-2007
SD-2	Drainage East District	Priority projects to improve existing drainage canals and provide new roads and drains in urban growth areas. Siem Reap City drainage master plan, river erosion and flood control project. *Project proposed by AFD;* *Funding commitment 3.5 million EUR.*	APSARA/ DPWT	2006-2009

Table III.9.40 Project Identification (Cont'd)

SD-3	Sewerage & drainage West District Zone 1	Install separate wastewater collection system. Connect sanitary sewers to the interceptor sewer provided under project SD-1. Provide new storm water drainage pipes from central market and old market areas. Includes capacity building for O&M of sewerage facilities.	MPWT/ DPWT	2006-2010
SD-4	Sewerage East District Zone 1	Provide a separate wastewater collection system for zone 1 and treatment plant located south-east side. Includes capacity building for O&M.	MPWT/ DPWT	2008-2012
SD-5	Drainage West District	Storm water relief: provide new western drain to relieve flows in town center drain and improve drainage in extended urban growth areas, divert catchment areas to relieve flows in town center drain	MPWT/ DPWT	2009-2012
SD-6	Septic sludge disposal West District	Provide septage collection vehicles and construct septage treatment facility at the wastewater treatment plant provided under SD-1. Includes technical assistance for developing a septage monitoring unit.	MPWT/ DPWT	2012-2014 Dependent on SD-1
SD-7	Septic sludge disposal East District	Provide septage collection vehicles and construct septage treatment facility at the wastewater treatment plant provided under SD-4. Includes technical assistance for developing a septage monitoring unit.	MPWT/ DPWT	2014-2016 Dependant on SD-4
SD-8	Septic tank effluent disposal West District Zone 2	Install simplified pipe system for collecting and conveying septic tank effluent to trunk sewers installed under SD-3. Expand existing pumping station and treatment capacity.	MPWT/ DPWT	2015-2018 Dependent on SD-3.
SD-9	Septic tank effluent disposal East District Zone 2	Install simplified pipe system for collecting and conveying septic tank effluent to trunk sewers installed under SD-4. Expand existing pumping station and treatment capacity.	MPWT/ DPWT	2016-2019 Dependent on SD-4.

9.3.3 Project Timing and Implementation Sequence

The following flow chart explains the sequence for project implementation.

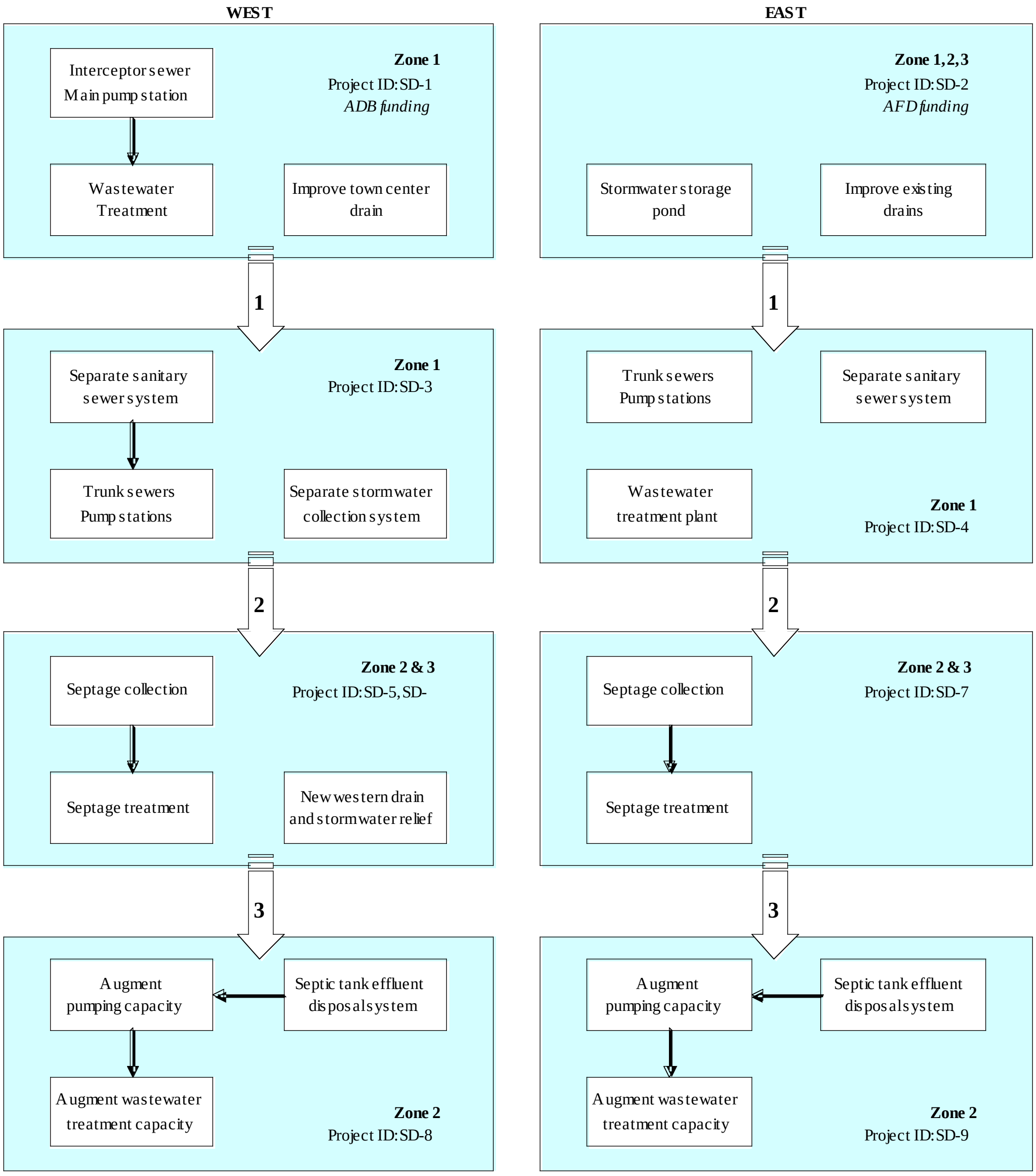

Figure III.9.14 Project Implementation Sequence

The implementation of projects in the East can proceed independently from the West. At each step priority is given to completing projects in the West district. A time lag of two years is recommended before doing the same type of project in the East in order to gain experience and make adjustments from lessons learned.

The timing for implementation of sewerage and drainage development depends on future growth trends. However a number of projects will be required in the immediate future to address conditions that have been created by recent rapid growth. These projects are SD-1 to SD-5. It would be preferable if these projects proceeded as soon as possible and were completed by 2012.

The first two projects (SD-1 and SD-2) are already under way with funding from the ADB and AFD. The project undertaken by ADB on the west side will address the urgent need for improved drainage in the central urban area where there is a higher population density and a higher percentage of developed (paved) area and thus more runoff. It will also provide the backbone infrastructure sewerage collection and treatment. Drainage improvements proposed by AFD on the east side are equally urgent. The area is being urbanized at a rapid pace and the formal construction of roads and drains should proceed as soon as possible while land and road allowances are still available. Drainage improvements should be coordinated with the construction of roads which have been proposed as priority projects.

The next project on the list (SD-3) should be implemented in parallel with the ADB project. It is identified as a priority project because the rapid pace of development has created an urgent need to protect water quality and public health in the densely populated urban core where septic tanks are not feasible.

The project will provide separate wastewater collection systems in the urban core (Zone 1-west) including house connections. Separate sanitary sewers provided under the project will be connected to the trunk interceptor sewer provided under ADB project SD-1 and conveyed to the new treatment lagoon south west of the city. The system of stormwater collection pipes will be rehabilitated and improved to reduce localized street flooding.

The need for sewerage (SD-4) on the east side is becoming urgent. The rural character or this area is changing quickly as the urban area has started to expand in this direction. The densely populated core along the river and NR6 will soon need a separate sewerage system to prevent environmental degradation to the river and in downstream rural areas.

Project SD-5 will provide a new drain in the west and stormwater sewers to relieve flows in the Town Center Drain. This project should be implemented while land is still available. The new drain is required to remove stormwater drainage in growth areas which are rapidly being developed to the west. Continued development of the urban core will result in more impervious surfaces and therefore more stormwater runoff. The amount of runoff generated in the center core will probably exceed the hydraulic capacity of the town center drain. Stormwater flows in the TCD can be relieved by diverting upper catchments in the urban core to the new drain.

The proper management of septage (SD-6 and SD-7) will become more important as the population increases. The implementation of sewerage in the densely populated urban core will eliminate part of the problem by phasing out septic tanks in zone 1. Septage treatment facilities will be constructed at wastewater treatment plants implemented at earlier stages. The septage treatment process will separate solids from liquids. Regular collection and disposal of septage should not proceed until the wastewater treatment plants are receiving sufficient flows to dilute the liquid portion of septage. The development of GIS database and septic tank registry required for proper administration of septage collection should begin 1 year before the construction of the treatment facilities. Proper management and installation of septic tanks should reduce the impact of septic tanks on groundwater contamination and will help maintain sanitary conditions in less densely populated urban areas.

Eventually the sewerage system will need to be expanded (SD-8 and SD-9) to collect wastewater flows from zone 2. The sewer system installed at an earlier stage will be expanded to collect the liquid effluent from septic tanks using a system of smaller diameter sewers. The timing for this expansion will depend mainly on population growth and density, as well as environmental conditions at the time. The project should be implemented sooner if sanitary conditions in zone 2 become unfavourable.

9.3.4 Land Acquisition

The most urgent needs for infrastructure are in the densely populated central urban core on both sides of the river. However development is moving at a rapid pace and it would be wise to proceed with land acquisition and the development of roads and drains to prevent the chaotic development that can be seen elsewhere in the city.

Early land acquisition is considered a priority. The recent construction boom has driven investors to buy land on speculation and the costs have risen dramatically. Waiting to buy land will only add to the cost of implementing projects.

9.3.5 Estimated Project Costs

Preliminary project cost estimates are based on the following conditions and assumptions:

- Import duties are included in direct costs
- Physical contingency is 10% of total direct costs
- Costs are in US dollars at 2005 base price.
- Price escalation is10% of total direct costs
- Engineering services for feasibility study, detailed design and services during construction is 10% of direct cost including physical and price contingency
- Value added tax (VAT) is not included in the estimated cost
- Land acquisition includes compensation costs and is estimated using a unit price of $30/m2 in the urban area within the ring road, $10/m2 in the peri-urban area outside the ring road and $5/m2 in rural agricultural areas.

Annual operating and maintenance costs are discussed in the section of the report that deals with organization and management of O&M.

Table III.9.41 Estimated Investment Costs for Sewerage and Drainage Development

(US$ '000)

Project ID	SD-1	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-9
description	Drainage		Simplified sewerage		Drainage	Septage management		Septic tank effl. disposal	
District	West	East	West	East	West	West	East	West	East
Zone	1	1,2,3	1	1	2,3	2,3	2,3	2	2
Civil Works									
Drains/ canals	1,718	3,100	0	0	2,500	0	0	0	0
Stormwater collection pipes	0	0	3,500	0	5,500	0	0	0	0
Trunk sewers	1,847	0	1,793	3,820	0	0	0	1,610	120
Branch sewers	0	0	5,040	5,180	0	0	0	4,380	2,790
House connections	0	0	321	0	0	0	0	674	657
Pumping stations	154	0	537	629	0	0	0	200	0
Rising mains	0	0	1,211	1,300	0	0	0	1,331	1,059
Wastewater treatment plants	3,123	1,250	0	1,455	0	0	0	1,091	728
Septage treatment plants	0	0	0	0	0	29	19	0	0
Sub-total	6,842	4,350	12,402	12,384	8,000	29	19	9,286	5,353
Equipment									
Mechanical & Electrical equip.	456	0	230	315	0	2	1	34	23
Vehicles	221	135	645	0	0	570	390	330	330
Mtce. tools and equipment	42	27	100	100	0	100	100	73	73
Sub-total	719	162	975	415	0	672	491	437	426
Total Direct Costs	7,561	4,512	13,377	12,799	8,000	700	510	9,723	5,779
Physical Contingency (10%)	756	451	1,338	1,280	800	70	51	972	578
Price escalation (10%)	756	451	1,338	1,280	800	70	51	972	578
Total construction cost	**9,073**	**5,414**	**16,053**	**15,359**	**9,600**	**840**	**612**	**11,668**	**6,935**
Engineering (10%)	907	541	1,605	1,536	960	84	61	1,167	693
Training/ technical assistance	0	0	660	375	375	690	345	0	0
Project Cost	**9,981**	**5,955**	**18,318**	**17,270**	**10,935**	**1,614**	**1,018**	**12,834**	**7,628**
Land acquisition by MEF/MPWT	2,000	4,000	750	2,250	1,000	0	0	300	0