

Guidelines for Planning and Development of Human Settlements in Urban and Rural Areas of Bhutan to minimise environmental impacts



Department of Human Settlement
Ministry of Works and Human Settlement
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Foreword

The rapid rate of urbanization and socio-economic changes taking place in the country could have an adverse effect on the environment and the people's way of life. Unplanned developments are taking place rapidly which could also lead to loss of habitat, traditional settlement patterns and architecture of Bhutan.

Besides, Bhutan being located in an extremely fragile terrain is highly susceptible to numerous natural and climate change related hazards such as extreme weather patterns, floods, earthquakes and landslides. In addition, rapid urbanization could lead to loss of prime agriculture land, land degradation, encroachment into forestland and water resource. Developments may extend to steep terrain with increased risks of natural disasters or located along the river valleys that are prone to Glacial Lake Outburst Floods (GLOFs), flash floods and landslides. Climate change could also significantly undermine development by threatening critical resources, especially water, and increasing the incidence and severity of natural disasters.

Given the urgency of the problem, it is essential to reduce greenhouse gas emissions through mitigation and pursue climate/disaster resilient development. Lack of environment, climate change and poverty mainstreamed guidelines/codes in the preparation of development plans and layouts for human settlements both in urban and rural areas increases the vulnerability of the population, particularly the poor who depend mostly on environment and natural resources for their livelihood.

Therefore, the primary objective of the study was to develop a framework of guidelines for human settlement in both urban and rural areas by mainstreaming Environment, Climate Change and Poverty (ECP). The guidelines focus on promotion of eco-friendly technologies, conservation of natural environment, management of environmental hazards (resilience planning). The best practices in planning and construction practiced in other parts of the world is also covered in the guideline.

This guideline has been prepared by The Energy and Resources Institute (TERI) based in New Delhi with the funding from the Joint Support Program (JSP). The project was led by Dr. Hina Zia and supported by a team of Engineers and Urban Planners from TERI and advised by Mr. Pradeep Kumar. From the Department of Human Settlement, Mr.

Kinzang Norbu, Director has been the guiding force in the formulation of this guideline; Chief Urban Planner, Mrs. Latha Chhetri has supported and guided the team as a project coordinator in smooth preparation of the guidelines. Ms. Kinzang Deki, Project counterpart, has worked very hard with commitment and zeal.

We would like to express our indebtedness and our sincere appreciation to the following persons for support, cooperation and assistance received for developing this report: Mr. Karma Tshering, Director, Department of Renewable Energy; Mr. Yeshey Dorji, Department of Geology and Mines; Mr. Sonam Wangchuk, Chief Forestry Officer, Department of Forests and Park Services; Ms. Nagtsho Dorji, Conservation of Architectural Heritage Sites Division, Department of Culture; Mr. Tashi Wangchuk, BSB; Mr. Karma Jamtsho, District Engineer, Thimphu Dzongkhag Administration, Mr. Rinchen, National Housing and Development Corporation, Mr. Jigme Dorji, Head, Development Control Division, Thimphu Thromde and officials of National Environment Commission. Besides them, an active contribution of various stakeholders during the consultation workshop is deeply appreciated.

In conclusion, the MoWHS would like to urge all the stakeholders and implementers to extend their cooperation and support to enable us in making optimum use of this guideline for planning and development of Human Settlement, while carrying out their day to day responsibilities.



(Dr.) Sonam Tenzin

Secretary, MoWHS

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Guidelines		Development Typology Applicability	
Code	Section	Rural Areas	Urban Areas
SECTION 1: SUSTAINABLE SETTLEMENT ENVIRONMENTAL PLANNING			
Guideline 1.1	Site Assessment	√	√
Guideline 1.2	Planning the Development	√	√
Guideline 1.3	Retaining natural vegetation	√	√
Guideline 1.4	Revegetation and Landscaping	√	√
Guideline 1.5	Transport planning	√	√
Guideline 1.6	Earthworks and Grading	√	√
Guideline 1.7	Soil erosion and sedimentation control	√	√
Guideline 1.8	Preservation of flora and fauna	√	√
Guideline 1.9	System approach adoption for land-use plan	√	√
Guideline 1.10	Visual Quality	√	√
SECTION 2: ENERGY AND ENERGY SYSTEMS			
Guideline 2.1	Architectural Planning & Design	√	√
Guideline 2.2	Renewable Energy Systems	√	√
Guideline 2.3	Electricity distribution network		√
SECTION 3: ENERGY EFFICIENT STREET LIGHTING			
Guideline 3.1	Energy efficient street lighting		√
SECTION 4: WATER AND WASTEWATER MANAGEMENT SYSTEMS			
Guideline 4.1	Sustainable water	√	√

Guideline 4.2	management		
	Sustainable wastewater management	✓	✓
Guideline 4.3	Sustainable stormwater management	✓	✓
SECTION 5: SOLID WASTE MANAGEMENT			
Guideline 5.1	Organic/Biodegradable waste treatment	✓	✓
Guideline 5.2	Construction & Demolition waste management		✓
SECTION 6: RISK MITIGATION/ADAPTATION AND CLIMATE CHANGE			
Guideline 6.1	Planning for climate change adaptation in all settlements	✓	✓
SECTION 7: BUILDING MATERIALS AND CONSTRUCTION TECHNOLOGIES		✓	✓

Introduction

1.1 Aim/objective

- ▶ The primary objective of the proposed study is to develop a framework of guidelines for human settlement in both urban and rural areas by mainstreaming Environment, Climate Change and Poverty (ECP)
- ▶ The guidelines focus on promotion of eco-friendly technologies, conservation of natural environment, management of environmental hazards (resilience planning).

1.2 Limitation

The study does not cover the mapping and forecasting of climate induced changes and vulnerabilities thereof in future with implications on settlement and buildings.

Preparation of detailed structure plan for the entire country is not within the purview of this study.

Due to time and resource constraint, primary data collection for energy consumption data for various building types, construction typologies, inventory of building materials suppliers, etc., is not included as part of this study. Instead, several interview/ interactions were conducted with officials of key ministries and departments for an overview of these aspects. Key departments and ministries contacted with the help of Department of Human Settlement are:

- Thimphu Municipal Corporation
- Dzhongkhag Engineer, Thimphu Dzhongkhag
- Bhutan Standards Bureau
- Department of Hydromet Services, Ministry of Economic Affairs
- Department of Geology and Mines, Ministry of Economic Affairs
- Department of Agriculture, Ministry of Agriculture & Forests
- Department of Renewable Energy, Ministry of Economic Affairs
- Department of Forest and Park Services, Ministry of Agriculture & Forests
- National Environment Commission
- Department of Culture, Ministry of Home & Cultural Affairs
- National Housing Development Corporation

Based on the methodology proposed as part of the **Inception report**, these draft guidelines have been prepared.

GOAL SETTING

Prior to moving on the section on Guidelines for Settlements, goal setting is very important. The overarching goal of course, remains the achievement of sustainability in every aspect. One important aspect which a local authority (especially in the context of urban centers) can look at is the carbon footprint of the settlement/ city.

TARGETED CARBON FOOTPRINT and Measurement and reduction of Settlement carbon footprint

In the context of increasing concerns about climate change impacts of increasing levels of carbon emissions in atmosphere, it has become critical to plan for low -carbon growth of urban areas as they contribute towards a significant share of carbon emissions. Retrofitting exiting urban settlements to reduce their carbon impact is a daunting task for the city planners; however, the new urban developments that are coming up in the country can make a contribution towards achieving the goal of low -carbon growth. To do this, the new developments have to be planned in a manner that they minimize use of fossil fuels to sustain the activities that are planned to come up within their premises. The key interventions that can be taken include:

1. Reducing and optimizing energy use in buildings
2. Reducing and optimizing energy use in provision of services like water pumping, etc.
3. Promoting use of alternative clean fuels like solar energy, wind energy, etc.
4. Reducing use of personalized motorized transport within the development by-
 - a. Providing adequate and quality infrastructure for walking and cycling
 - b. Providing mass transport options that run on clean fuels
 - c. Promoting use of clean fuels in personal vehicles by providing adequate supporting infrastructure for use of clean fuels

In order to fix the targeted carbon footprint, it is proposed to look at per capita basis in order to compare it with national average values and/ or other cities.

For instance, the per capita carbon estimate for Bhutan was 0.55 tonnes, nearly one-eighth of the corresponding global average of 4.55 tonnes. Per capita carbon footprint estimates for various neighbouring Indian cities in 2007-08 was also done by ICLEI as part of a study.

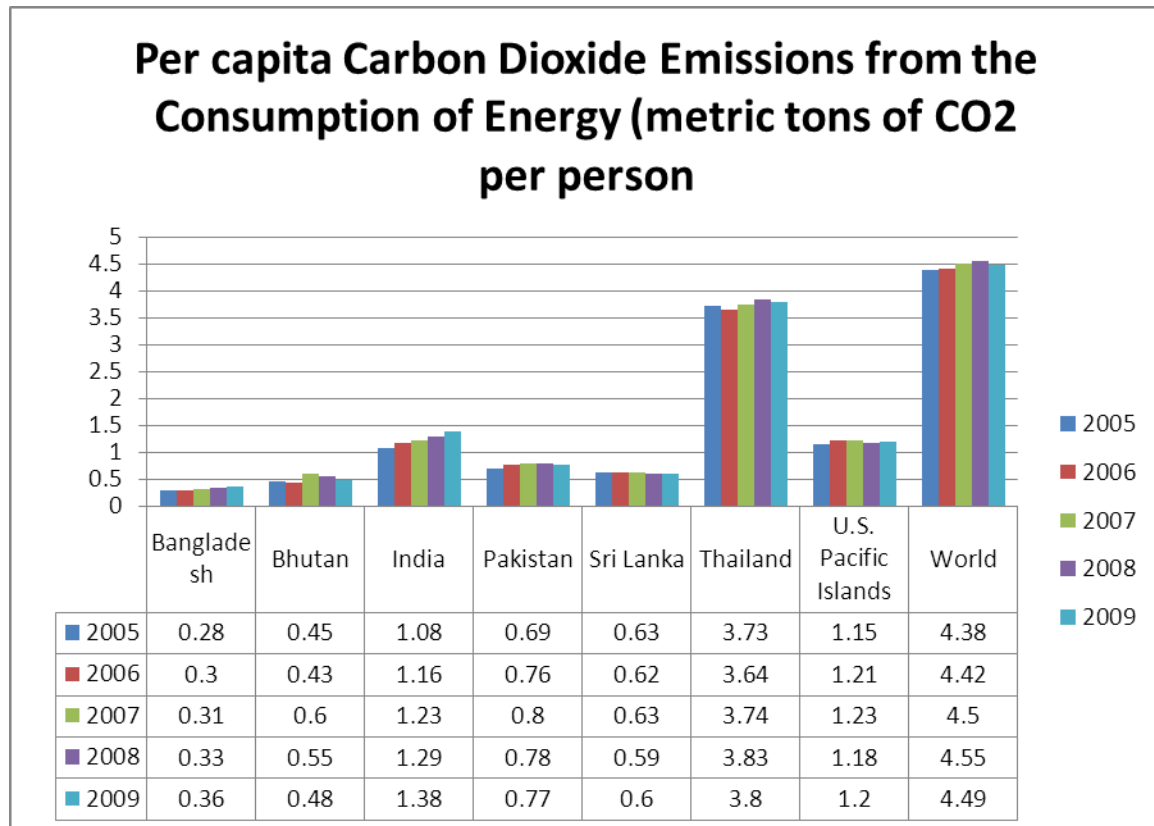


Figure 1 : Per capita carbon emissions in Bhutan and other countries

(Source: <http://tonto.eia.doe.gov/cfapps/ipdbproject>)

The per capita carbon emissions from the use of energy has shown a decreasing trend from 2007 onwards in Bhutan. Similar data needs to be generated for urban centers to keep a target below the national level benchmark. This has been adopted by many cities across the world to map their emissions every year and accordingly define their targets/ vision.

Once a targeted footprint has been set (for the time being national standard can be taken as the benchmark), all the local authorities for urban centers shall aspire to achieve the targeted carbon footprint through various interventions.

Carbon footprint is defined as the total 'carbon dioxide equivalent' (CO₂e) emissions released from energy use within a development/city/state/country/sector.

1. Estimate the total energy consumption within the settlement

Table 1 : Energy consumption for the following activities needs to be estimated:

Activity	Total Energy consumption
Building operations	Electricity – from grid Electricity – from off-grid sources
Services	Electricity – from grid Electricity – from off-grid sources Other sources – LPG, natural gas, etc.
Transportation within the settlement	Petrol Diesel CNG Auto-LPG Electricity – from grid Electricity – from off-grid sources Others
Electricity generation (if electricity is being generated on-site)	Fuel consumption for electricity generation

2. Estimate the carbon emissions from energy use

In order to estimate the carbon emissions from energy use, the total energy consumption figures obtained in the previous step need to be multiplied by respective emission factors. Tables below give values for Bhutan-specific emission factors.

$$CF = \sum E_i * EF_i$$

where,

CF = Carbon Footprint

E = Energy consumption

i = Energy type (electricity, petrol, diesel, CNG, etc.)

EF_i = Emission factor specific to fuel type 'i'

Table 2: Electricity emission factors (tCO₂/MWh)

Average	
Bhutan	1.004

Source: IGES, List of Grid Emission Factor, 2010. Institute of Global Environmental Strategies

For Bhutan-specific CO₂ emission coefficients of road transport (conventional and non-conventional), one can refer the tool developed by NEC as part of the ADB Technical Assistance (Japan Government Funded) capacity building of NEC for Transport Sector or take IPCC,2006 recommended world average numbers.



The carbon emissions estimated based on the total energy consumption of the settlement will indicate the impact that the settlement has in terms of carbon released. Based on the estimate, comparison has to be made with the national level benchmarks and strategies may be arrived at by the local authority to reduce the same in short term and long term and indicate their commitment to low carbon growth.

GENERIC PRINCIPLES TO BE FOLLOWED FOR ALL SETTLEMENTS

Settlements seeking special care:

Bhutan is located in one of the very seismically active zones of the world. Being the boundary zone of the two plates, Indo-Australian and Eurasian, seismic activities are very prominent. Delicate weak rocks, steep terrain, torrential rain, seismic movement, extensive soil erosion due to construction practices, all lead to aggravating the landslide related hazards (increasingly experienced in Bhutan) followed by flash floods.

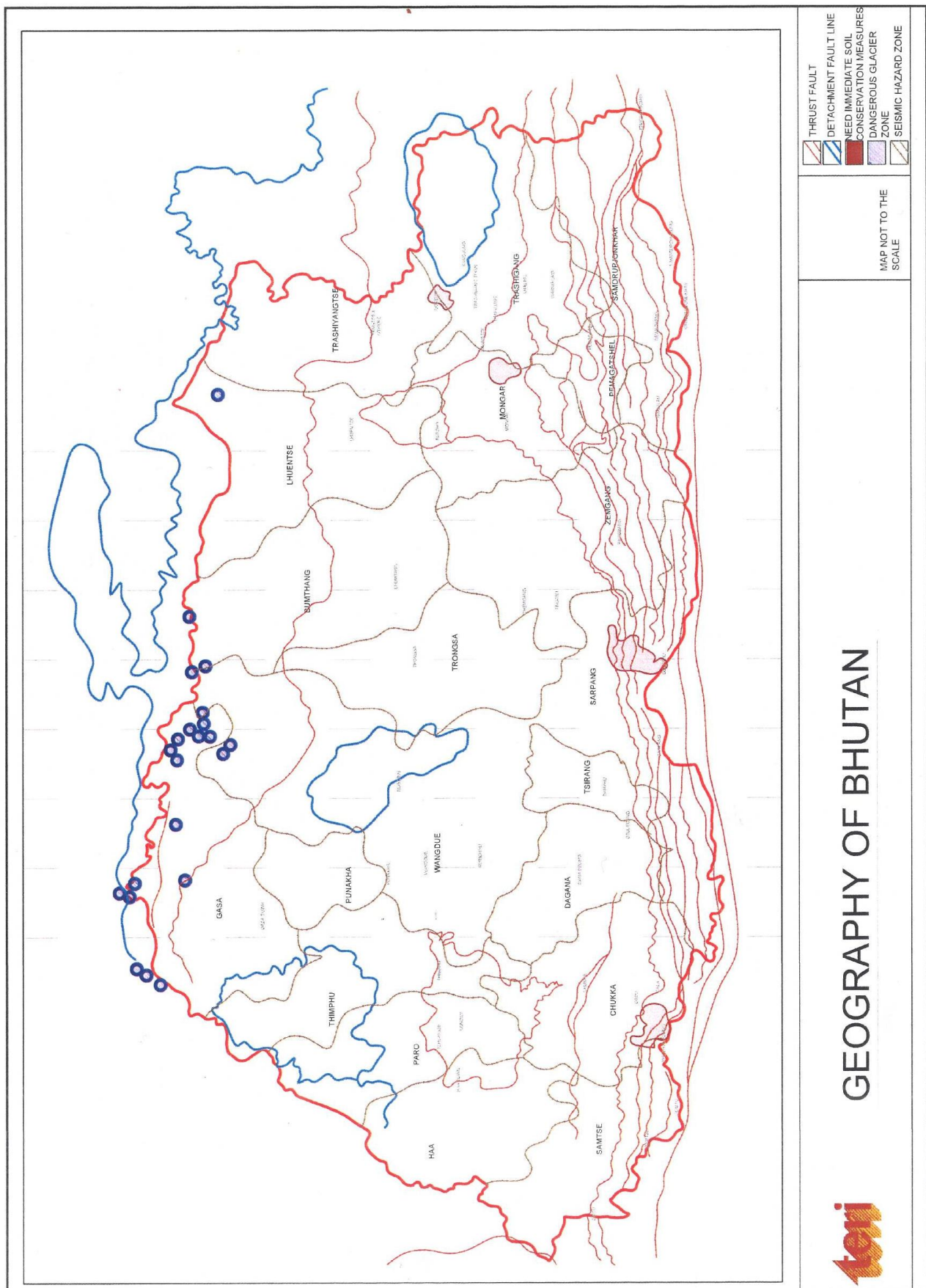
The adjoining map shows the areas prone to fault lines and earthquakes, glacier lake outburst, areas which have already suffered substantial soil erosion, biological corridors, national parks and rivers. Any settlement coming up in these areas need special attention and care and the respecting local authority shall consider all precautions to be followed in case any construction is allowed in such areas.

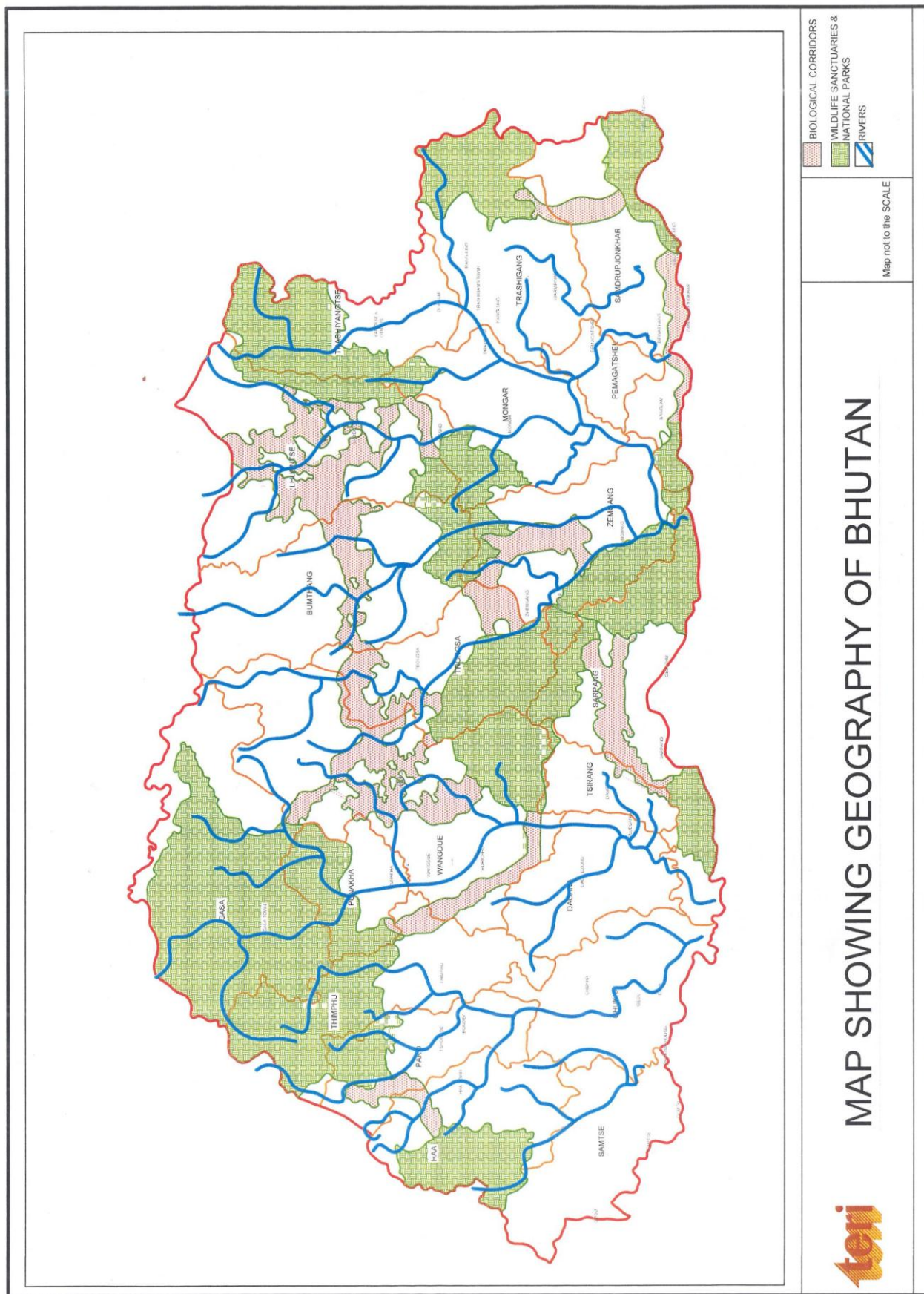
- All areas highlighted in red in the Figure need immediate intensive soil conservation measures. These have far fetched effects on the downstream areas and lead to instability of slopes.
- All streams across the country shall have a compulsory buffer of at least 200 ft on either side.
- Mandatory River bank protection measures to be adopted for all new settlements in rural and urban areas.
- For all existing settlements, phase wise plans to protect the river banks should be drawn by all the local authorities, dzongkhags and geogs.
- Clustered v/s scattered settlements

Clustered settlements are preferred over scattered settlements as the latter endanger the agricultural land, require high investments for new infrastructure, resource intensive maintenance and renewal. All new settlements should preferably follow a clustered approach. However, given the terrain characteristic and land ownership pattern, it may be difficult to implement in entirety.

- For hotels, resorts, group housing, hostels, educational institutes, etc., coming in non-planned areas, it is strongly recommended to ask the project proponents for the following prior to giving approval for construction:
 - a. On-site sewage management
 - b. On-site storm water management
 - c. Adoption of energy efficient measures

- d. On-site treatment of municipal solid waste and arrangements for safe disposal of other kinds of waste in compliance to the Waste Management and Handling Regulations 2012
- e. Appropriate adaptation/mitigation strategy in case the site is located in any vulnerable areas (as broadly marked in the adjoining map)
- f. Construction and Demolition waste management plan (for execution during the construction stage)
- g. Also, occupancy certificates should be provided only after checking the installed facilities in conformance to that proposed by the project proponent at the design stage.





OBJECTIVES

The proposed Guidelines are intended to impact design features to protect the natural environment by providing policy and regulatory direction for environmentally sensitive development in Bhutan. The objectives can be separated into four major categories which these Guidelines attempt to address: 1) Site and Subdivision Design, 2) Works and Services, Infrastructure 3) Buildings and Structures, and 4) Natural Environment.

1) SITE AND SUBDIVISION DESIGN

- a. Identify and incorporate significant site features in subdivision design. Proposed development layout and the typical building site design must acknowledge these natural features. This is required to:
 - develop an understanding of the environmental and geological conditions of the site prior to any construction to ensure that the most appropriate methods are used to develop the site; and
 - preserve and protect unique natural features which are a characteristic feature of Bhutan.
- b. Undertake subdivision planning and design that respects the existing natural area's terrain and hazardous conditions, while enhancing the area's natural character. This is required to:
 - enable subdivision planning and design that allows as much undisturbed native green space as possible on a site;
 - direct more development density to the less sensitive and flatter sections of a site, thereby creating clusters of development which avoid ecologically sensitive areas¹;
 - ensure that steeper portions of a site (with an existing slope of 30% or greater) are not included in the developable area calculation; and if allowed (as less steep slopes may not be readily available in Bhutan) should preferably be done with necessary precautions
 - minimize the impact of grading and retain as much of the natural topographic character of the site so that natural vegetation and other features remain undisturbed in order to protect ecological values, maintain slope stability and provide aesthetically pleasing views.

This needs to be integrated with the EIA clearance procedure for all developmental activities from NEC.

¹ Such ecologically sensitive areas (other than the protected areas) need to be identified by the RGoB

- c. Protect and preserve the scenic characteristics of hills and places identified under heritage/ conservation plan (under process by the Department of Heritage Conservation) This is required to:
- ensure significant ridgelines ²visible throughout the development are protected thereby maintaining the natural appearance of skylines for public enjoyment and benefit; and
 - maintain the conservation character of heritage villages and sites

2) WORKS AND SERVICES

- a. Implement methods for collection, conveyance, control and treatment of storm water that mitigates potential impacts and emulates the area's natural water cycle. This is required to:
- limit runoff from new development based on the soil capacity and sensitivity for ground recharge and overland conveyance.
- b. Integrate onsite design which compliments the streetscape design. This is required to:
- ensure works and services are suited to the development proposed and support the streetscape required for creation of a people orientated neighbourhood contrary to the conventional practise of vehicle oriented settlements.
- c. Provide municipal services and utilities on hillside developments that minimize redundancy and provide cost efficient maintenance and future replacement. This is required to:
- ensure that development on hillsides does not result in financially unsustainable increases in infrastructure relative to the number of units created, (i.e. single loaded roads or service mains that only cater to market objectives); and
 - ensure comprehensive design of water and sewer systems based on ultimate land use and topography. The service life of proposed infrastructure must be considered when examining the limitations of required works. This is required to ensure the scope of initial works is consistent with proposed phasing and does not facilitate installation of works that will have no or minimal use during their service life.

² A ridgeline is the continuous line that demarcates the contrast between the sky or distant hills and the earth

3) BUILDINGS AND STRUCTURES

- a. Hillside zoning recognizes the unique nature of hillsides and governs onsite coverage and setback issues necessary to provide livable neighbourhoods that are not dominated by vehicles or buildings. This is required to:
- provide flexible front and side setbacks that reduce the amount of cutting and filling required, and support level entry and good street presence;
 - provide a less “imposing” character on surrounding developments; and
 - provide opportunities on the newly created lot for the planting of trees that will eventually mature and contribute towards the long-term aesthetic character of the development as viewed from the rest of the settlement.
- b. Avoid over height buildings and minimize the visual impact of new buildings on hillsides.

4) NATURAL ENVIRONMENT

- a. Minimize slope alterations and retain the natural terrain and topography of the site. This is required to minimize disturbance to natural vegetation, to maintain ecosystem integrity and protect natural buffers between development clusters with removals based on an intimate knowledge of the site
- b. Identify and protect significant organic and inorganic natural features and wildlife habitat corridors. This is required to ensure that natural features that support unique micro-ecosystems and provide habitat remain undisturbed and linked to other open space features such as ravines, forested areas and water supply.
- c. Plant vegetation that helps mitigate the impact of development enhances visual quality and addresses the needs of residents. It should ensure the use of indigenous local plants and tree species which can provide food and shelter for local wildlife, cost less to maintain, are drought tolerant and fire resistant.

SECTION 1: SUSTAINABLE SETTLEMENT ENVIRONMENTAL PLANNING/ SITE AND SUBDIVISION DESIGN

As mentioned in the earlier chapter, Bhutan is located in one of the very seismically active zones of the world. Geologically, it is fragile in terms of the stability of rocks, resulting in natural and human induced instances of landslides, flash floods, glacier lake outburst. Landslide is defined as a downward and outward movement of slope forming materials under the influence of gravity (Varnes, 1978). Although it is a natural process, it has been aggravated due to human activities, which disturb the slope stability (Rotaru, et al., 2007). There could be several factors triggering landslides, some of which is summarized in the following table:

Landslide triggers	Natural triggers	Human triggers
Removal of support	Erosion at the base of a slope by streams, waves, glaciers	Excavation at the base of a slope or excavation on a hillside
Removal of vegetation	Forest fire	Timbering
Addition of moisture	Rainfall or snowmelt	Sewage or runoff disposal, broken water pipes, improper grading
Addition of weight	Heavy snowfall, volcanic ash, landslides	Placement of fill
Over steepening (this term is used as removal of support)		Placing fill at a gradient that exceeds the angle of repose
Vibrations	Earthquakes, nearby landslides	Blasting operation of heavy equipment

Source: Rotaru, Oajdea and Raileanu (2007)

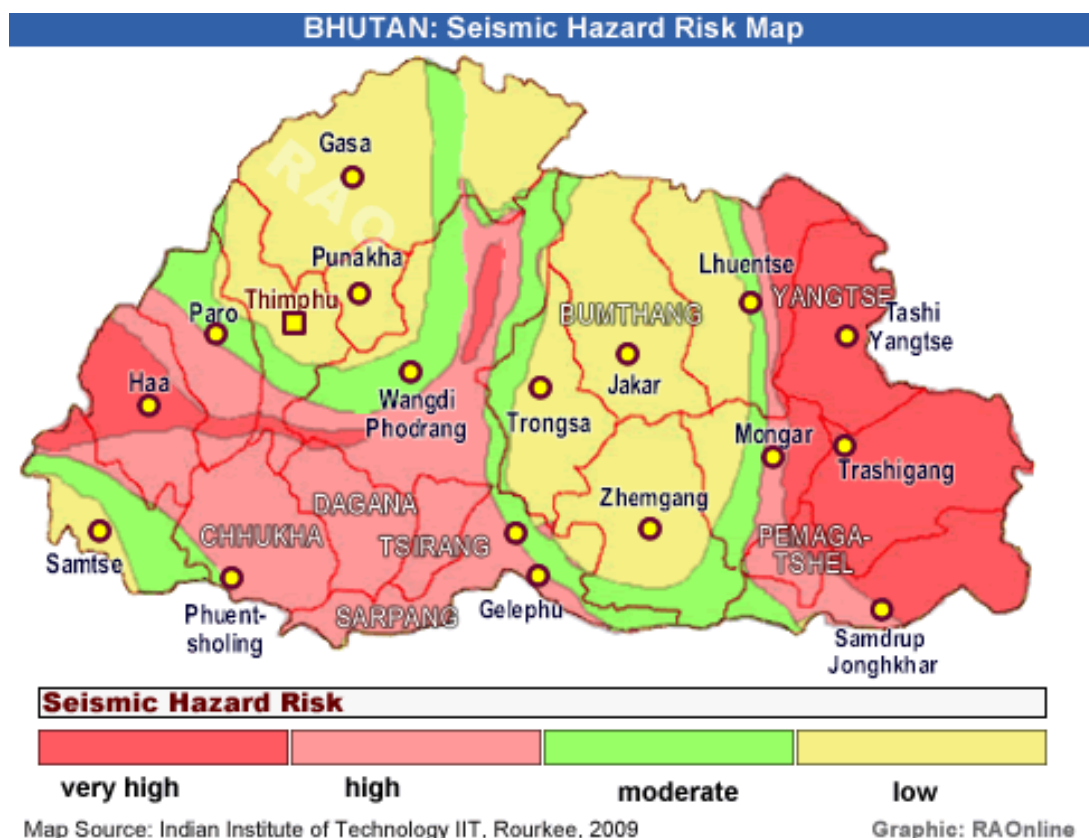
As observed in the table, amongst the human triggers most of them are directly or indirectly related to construction activities. Guidelines proposed under this section primarily focus on ameliorating or preventing such human triggers.

Guideline 1.1: Site Assessment

Site assessment is important prior to developing the building site and road design to acknowledge the hillside character and natural features of the site.

In case of new large settlement and campuses/ neighbourhood, following is recommended:

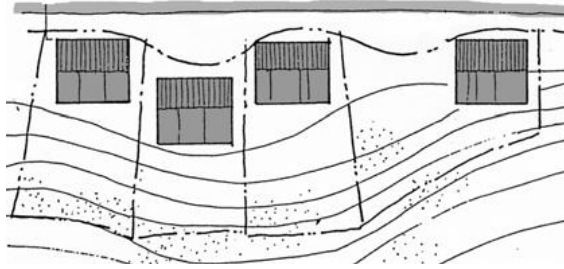
- A review including topographic survey to assess and plan the site in a manner that respects the slope and any special features present (e.g. stream, water body)
- A geotechnical assessment to identify and avoid hazardous areas. In case such study is not possible at a national level, it is strongly recommended to undertake a micro-zonation study and areas where no development can be taken should be earmarked and followed by the respective local authorities. A large portion of the country lies in very high to high earthquake prone areas and strict construction regulation (technologies and materials as recommended by the IS Codes) need to be followed specially in such areas.



- An environment assessment (base case as recommended in the EIA by NEC) to identify existing ecosystems and special natural/ cultural/ heritage features of a site. This helps in designing as per the site conditions, retain natural resources and allow for efficient construction and maintenance.

Guideline 1.2: Planning the Development

- No construction of high rise (G + 2 and above) buildings should be permitted for slopes greater than 30%. Although construction of even low storeyed buildings on slopes greater than 30% is not desirable but due to non-availability of enough land of less steep slopes, it is recommended to take all necessary precautions for such construction to avoid safety issues.
- Use building setbacks (where applicable) in a flexible manner to protect slopes and natural features from development encroachments. All the proposed setbacks and driveways need to be shown on grading plans.



Guideline 1.3 : Retaining natural vegetation

Existing vegetation on steep slopes is not only important to the ecological and aesthetic values of the site, but also plays an important role in the maintenance of slope stability, drainage and erosion prevention. The decision to retain or remove vegetation should therefore, be based on an intimate knowledge of the site.

- It is recommended to use varied lot size and configuration, to retain tree stands and other vegetation communities to preserve environmental value (e.g., habitat, biodiversity, heritage trees, etc), maintain soil stability, provide a buffer between development areas, and define neighbourhood character.
- Make strategic use of existing vegetation to retain the site's natural character.
- Phase land clearing to minimize the area exposed to soil loss and erosion at any one time. Phasing may be service related (eg, clear initially only enough to install

roads and main service lines), or spatially related (ie, clearing only one portion of the plot at a time, completing development and revegetation to control erosion before starting the next portion). For further details refer the soil erosion and control guidelines.

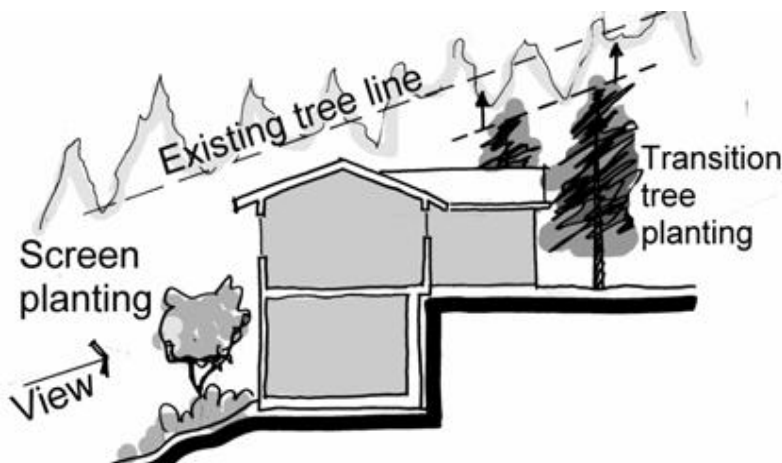
- For areas of the site where vegetation must be removed but no construction will occur, leave soil intact (ie, avoid compaction, excavation, filling, etc) to allow for more successful replanting in these areas.

Not only do site disturbances (cut and fill, clearing, compacted soil, dump sites, eroded areas, etc) have short-term impacts but, if not properly treated, these disturbances may have long-term negative impacts on personal safety, property and the environment.

Guideline 1.4: Revegetation and Landscaping

Following is recommended under this guideline:

1. Replace trees in a manner that helps to restore the natural character of the hillside site. Specifically, plant trees to screen undesirable views and buffer incompatible uses. Arrange trees in natural groupings or clusters rather than in lines or formal arrangements.



Source: Steep Slope Development Guidelines, City of Nanaimo

2. It is strongly recommended to use native plants for site restoration and landscaping as much as possible. Where the use of native plants is not desirable given site or view constraints, select naturalised plants that is similar in appearance, growth habit, colour and texture to native plants, and that will not

- act as a “weed” in the natural environment (i.e., it will not out-compete native plants, provide habitat for undesirable wildlife, or act as a host for insect pests).
3. Plant shrubs and trees in masses and patterns characteristic of a natural setting and with the intent of encouraging biodiversity.
 4. For restoration or creation of habitat areas (e.g. riparian areas, ravines, greenways, etc.) use plant species that have value as food or cover for wildlife.
 5. For dry or south facing slopes, replant with drought and fire-resistant species. If list of such species is not available, the concerned department of Agriculture and Forestry may provide such list to the Ministry of Works and Human Settlement for integration with building rules and bye-laws at all levels (including rural settlements).

Guideline 1.5: Transport planning

- Roads and Lot Layout

Straight lines and rectilinear shapes generally do not complement natural hillsides. It is therefore, recommended to lay out roads and lots in a pattern that offers a variety of sizes and configurations that complement the topography and features of the site.

- Trails and Open Space

Retain open space and corridors between development lots to provide continuous habitat linkages within the site as well as with neighbouring sites. Use trails or linear systems to link parts of the hillside community which are not otherwise linked by roads due to topographic constraints. An open space, streetscape and trail system should be developed to provide pedestrian access within the hillside area and to/ from key destinations in other parts of the community (e.g., schools, commercial or town centers, parks, other trails, etc).

Guideline 1.6: Earthworks and Grading

This guideline is applicable for construction on sites of any scale (i.e., individual buildings, set of buildings, campuses, etc.)

1. In preparation of a grading plan the following must be considered:
 - Avoid grading or alteration of key topographic features (e.g. knolls, ridgelines, cliffs, ravines, etc).
 - Avoid sharp cuts and long or wide slopes with a uniform grade. Graded slopes should not have a typical manufactured look rather an organic natural look.

Guidelines for Planning and Development of Human Settlements in Urban and Rural Areas of Bhutan to minimise environmental impacts

- Establish contours and gradients that resemble the naturally occurring terrain. Round out slope transitions and blend transitions between lots or adjacent to undisturbed areas.
- Refrain from grading large flat terraces on hillside sites in order to expand developable area or to develop housing or other uses characteristic of flat or gently-sloped sites. Developing smaller terraces (eg, for building pads, stepped retaining walls, etc) is preferred.

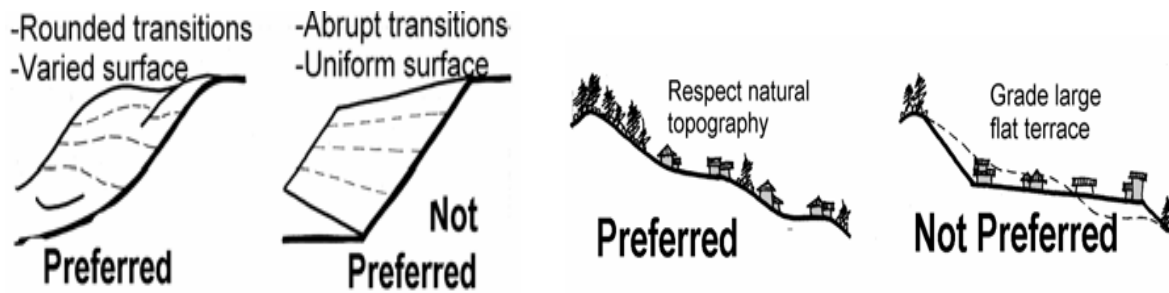


Figure 2 : Current practice of grading the entire site at one go

2. Cut and Fill

In designing and developing the site, minimize the total amount of cut and/ or fill and its environmental and visual impact by:

- Where the volume of cut exceeds the volume of fill material for a proposed development, it should not be disposed of on site in the form of unnecessary filling, or side-casting. Where necessary, dispose of excess material at appropriate off-site locations.

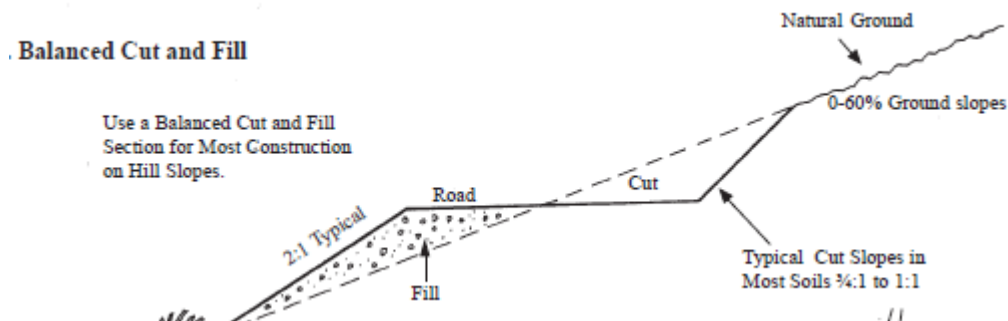


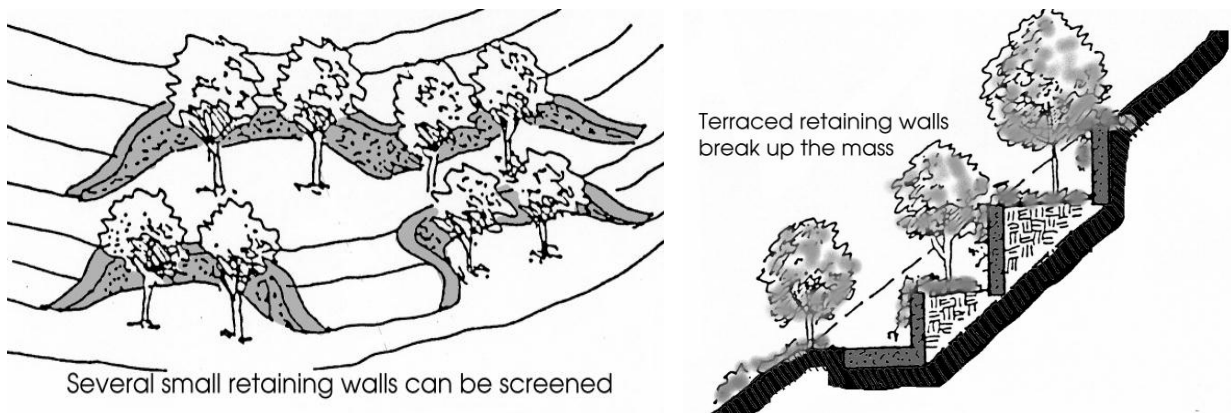
Figure 3: Balanced cut and fill approach for construction in slopes

- Re-vegetate exposed slopes as quickly as possible to prevent erosion and slope stability problems (Refer the section on guidelines for erosion control)

3. Retaining Walls

It is recommended to use retaining walls where they can reduce disturbing the slope to provide useable construction sites.

- Retaining walls should respect the natural character of the site and not be dominating.
- Retaining wall height may be limited to 3.0 metres for roads and site works, 1.2 metres for front plots, and 2.4 metres for rear and side plots from the perspective of stability. Higher walls may be appropriate where they are articulated, have a surface texture/ pattern, or where sufficient landscaping is provided at its base.
- Use of smaller stepped retaining walls over the use of a large uniform wall is preferred. The height and depth of the wall steps should be consistent with the natural terrain. For stepped retaining wall systems, landscape the intermediate terraces.



Guideline 1.7: Soil erosion and sedimentation control

When land is under construction, soil erosion can be significant – often many times greater than on land used for agriculture; it increases by 2-40,000 times the preconstruction rate. The resulting sediment damages surface water resources, obstructs roads and degrades wildlife habitat. Once developed, the land has more roofs, roads, parking lots and compacted turf. Impervious surfaces like these send more runoff across landscapes, and consequently, the risk of flooding is increased. Urban runoff impairs water quality in streams, lakes and wetlands by delivering sediment, nutrients, hydrocarbons and other pollutants. Ground water recharge is also reduced by impervious surfaces.



Figure 4 : Inappropriate soil erosion and sedimentation control

Prior to designing a subdivision or any other development, it is important that the developer take into account the slope & soil limitations of the site. This will facilitate a design that is economically and environmentally feasible. Once the limitations of the site are known, the developer can begin to design a development that is compatible with the natural environment. In areas prone to significant soil erosion and/ or sedimentation (which is primarily the case for most parts of Bhutan), the developer must implement a soil erosion and sedimentation plan of management. Erosion and sedimentation control can be broadly classified under three sections:

- A. Source Erosion Control** - stopping erosion before it starts, by keeping soil from being displaced.
- B. Runoff Control** - reducing the erosive energy of runoff and/ or conveying it using non-erodible surfaces.
- C. Sediment Control** - trapping runoff and reducing its velocity allowing sediment to settle.

A. Source Erosion Control Methods:

This is the most effective and economical way to keep soil on construction sites from getting eroded by minimising clearing and grading, and to keep exposed soil surfaces covered. This works on the fundamental principle of keeping soil from being displaced at the outset and is in fact, the first line of defence.

Suggested strategies to source erosion control are as follows:

1. Retained Vegetation:
 - Retaining the existing trees and plants is the best and lowest cost defence against erosion.
 - Places where clearing has to be done, grubbing of tree roots must be held back until grading is to proceed-the root mass provide substantial erosion control.
2. Clean water diversion:
 - Use strategies such as diversion swale above graded areas to direct clean water from undisturbed areas away from the grading activity. Swales must be gently sloped. For dispersing the swale runoff into vegetated areas, use rock apron or drainpipe to transport clean water to below the construction site.
3. Minimise disturbance area:

Only those areas should be cleared that must be graded in the current phase of development. For larger sites, grading and erosion control should be first completed in one area before proceeding to another. Vegetated areas must be left in place as long as possible to reduce erosion.

4. Slope Design:

Soil, runoff and groundwater conditions must be recognised when designing slopes. Saturated sand and silt soils are highly erodible. Erodible soil slopes over 2:1 must be avoided. 'Sheet' drainage is encouraged to avoid concentrated water flow down unarmoured slopes.

5. Surface roughening:

Surfaces should be roughened prior to seeding by using ploughing or machine tracking. This slows run-off and encourages infiltration which promotes germinations and plant survival.

6. Seeding and mulching:

Depending on the germination time, seeding must be done on disturbed areas. Use of local species is strongly recommended. Mulching is a temporary soil stabilization technique which may also be used. Mulch is simply a protective layer of a material that is spread on the top of the soil. Mulches can either be organic, such as grass, hay, straw, wood chips, and similar materials, or inorganic, such as stones and brick chips. Mulching should be used with seedlings and plantings in steep slope areas (slopes > 33%). Steep slopes are prone to heavy erosion. Netting or anchoring should be used to hold it in place. In addition to stabilizing soils, mulching reduces the storm water runoff over an area. Mulching when done with seedlings or plantings, aids plant growth by holding the seed, fertilizers, and top soil in place. It retains moisture and insulates the soil against extreme temperatures.



Figure 5: Good practice of netting and anchoring in one of the big construction project

7. Plastic Covers: Plastic covers may be used for short term cover of small areas when other methods are not feasible. However, for stockpiles not to be used for 2-3 or more days should always be covered by plastic covers or when rain is expected.

B. Runoff control methods

Runoff control methods reduce the erosive energy of runoff. The strategies to do this should decrease the amount of runoff, detain water to decrease the downstream velocity (decreasing the velocity of running water by $\frac{1}{2}$ reduces the erosive energy by 4 times), divert the runoff to less erodible areas and dissipate the runoff to facilitate 'sheet' runoff.

1. Catchment area control:

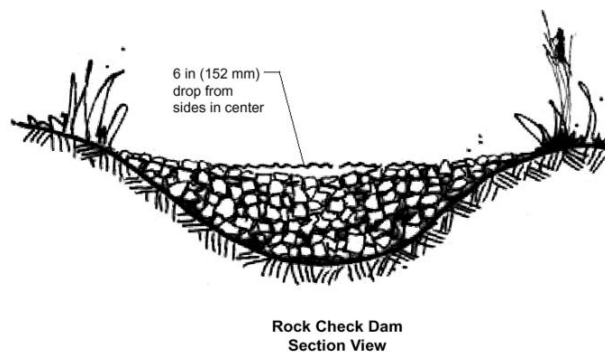
The site should be internally divided into small catchment areas (in case of large developments), to avoid concentrating large volume of runoff water. Collection and conveyance of runoff from each catchment area should be planned separately.

2. Slope Breaks:

Slope breaks are recommended for breaking the effective length of slopes. They are terraces with diversion swales or dykes, which collect sheet runoff from a catchment area and direct it to a slope drainpipe or other drop structure. Swales should be gently sloping and may include check dams, rock lining, or grass lining depending on the soil types and slope.

3. Check Dams:

Check dams are recommended to be used for both runoff control and sedimentation control. Steeper swales (>5% in stable soil) require check dams to slow the velocity and reduce erosion.



Check dams are usually made in rocks, sand bags, gabions (wire basket of rocks), straw bales, logs or interlocking pre-cast concrete blocks, depending

on the availability of local material. Non-erodible material (gravel, cobble, etc.) is recommended wherever water is concentrated (high velocity) or flows rapidly over the structure.

4. Grass swale/ rock channel lining:

Swales upto 5% gradient in stable soils must be grass lined, prior to exposing them to high flows. For channels with high runoff velocities, rock channel lining is preferred.

5. Slope drainpipes:

Slope drainpipes should be provided temporary or permanent to convey runoff from swales and channels down steep slopes. All necessary calculations should be done to size the pipe to match peak rainfall events.

6. Energy dissipators:

These are either precast concrete structures or riprap/ geotextile solutions. They may be provided at the outfall of drainpipes or high-velocity channels. It primarily reduces the runoff velocity and disperse the run-off.

C. Sediment Control methods

Some of the sediment control strategies are listed as under.

1. Sediment trap:

A sediment trap can be constructed by excavating a pond across a low-lying area on the site. The trap should retain the run off enough to allow the sediment to settle before they are released. The outlet is constructed using large stones and aggregate to slow down the release of run off. This system is appropriate for small drainage areas not more than 10 acres (Source: EPA, Chapter 3 – Sediment and Erosion Control). The volume of the storage required depends upon the surface type and rainfall intensity of the place.

2. Sediment Barriers:

Silt fence are the commonest sediment barriers employed with alternatives such as continuous berms of gravel or earth, straw bales, etc. A silt fence is a temporary measure for sedimentation control to detain sediments from a small drainage area. This system consists of a filter fabric which is supported by posts. The lower edge of the fence is vertically trenched and covered by backfill. This system is most effective where there is overland flow. It controls sediment run off from the site from entering into the receiving waters. For large areas, silt fence is not appropriate to control the run off; however, it could be used in combination with other erosion and

sediment control measures. The sediments should be removed and disposed once it is one third or one half the height of fence.

Sediment barriers should be installed to create ponded water-on flatter ground below exposed slopes, along the contour.

3. Sediment Basin/Pond:

Sediment basins are appropriate for disturbed site areas larger than 5 acres. A sediment basin could be defined as a settling tank with a controlled storm water release structure which is used to collect and store sediment produced from disturbed sites where construction activities are carried out. It is important that the basin size should be calculated to handle the maximum amount of drainage expected from the site. The embankment which forms the sedimentation pool should be compacted and stabilised with vegetation. The outlet of the basin should be as far as possible from the entrance to provide maximum retention time. The outlet should be a gravel outlet to slow down the run off and provide extra sediment filtration.

4. Gravel access pads:

Gravel access pads -20 cm thick layer of gravel should be provided at the site access to reduce the tracking of mud off the site onto adjacent roads, where it would eventually wash into the stormwater system or natural waterways.

These should be installed prior to use of heavy equipment or site grading operations and should be necessarily maintained throughout the construction operations. Trucks and materials/ equipment transporting modes should be restricted on these gravel access pads and gravel runways. Reinstallation of gravel access pads may be necessary on large construction sites.

5. All sediment interception traps/ponds must be inspected after each storm event and must have sediment removed regularly to maintain capacity.



Figure 6 : Some of the soil erosion and sedimentation control strategies

Guideline 1.8: Preservation of flora and fauna

The link between plants and wildlife is immense. Native plants, those which would naturally occur in an area of land without the interference of man, support a wide range of insects and animals. They also support other plant life. Wildlife and plants are inextricably linked and many insects for instance can only survive if a particular plant is present. Because of this strong link between plants, insects and other wildlife it is possible to predict which wildlife is likely to thrive if a given range of plant species is growing together.

Plants support most of the other life on earth by producing oxygen. They influence various aspects of the physical environment; in particular they are of major importance for the maintenance of air quality and can be used in microclimate control.

Following is recommended for preservation of vegetation and landscape on site -

- When developing the site, care should be taken to keep vegetation clearing at a minimum.
- Vegetation cleared should be monitored and documented in terms of area, species, densities / numbers of trees etc.
- Compensatory forestation should be practiced wherever vegetation removal has been done
- Mark existing vegetation on site in surveys and follow detailed guidelines of tree preservation.
- Protection of existing vegetation (including trees, shrubs, grasses and other plants) where possible, by preventing disturbance or damage to specified areas during construction is recommended. Preservation of natural vegetation acts a permanent control measure. It minimises erosion potential, protects water quality and provides aesthetic benefits. The technique is applicable to all soil types. Areas where preservation of existing vegetation are particularly beneficial are buffer areas, vegetated swales, steep slopes and stream banks, flood plains, and other areas where erosion control would be difficult to establish, install and or maintain.

All existing vegetation should be marked on a site survey plan. A tree survey in prescribed format should be carried out as indicated in Table-x. The landscape plan should indicate trees, which have been preserved, and also those, which had to be transplanted or removed clearly differentiating between these three categories.

Table 3 :Tree survey format

Serial No.	identifi able in survey plan	Botanical name	Com mon name	Girth	Heigh t	Spread	Conditio n	Protected/pr eserved /transplante d /removed

Trees retained on the project site should be protected during the construction period by following measures:

- Damage to roots should be prevented during trenching, placing backfill, driving or parking heavy equipment, dumping of trash, oil, paint, and other materials detrimental to plant health by restricting these activities to outside the area of the canopy of the tree.
- Avoid cut and fill in the root zones, through delineating and fencing the drip line (the spread limit of a canopy projected on the ground) of all the trees or group of trees. Separate the zones of movement of heavy equipment, parking, or excessive foot traffic from the fenced plant protection zones.
- Trees should not be used for support; their trunks should not be damaged by cutting and carving or by nailing posters, advertisements or other material.
- Lighting of fires or carrying out heat or gas emitting construction activity within the ground, covered by canopy of the tree should be avoided.
- Young trees or saplings identified for preservation (height less than 2.00m, 0.10m trunk girth at 1.00m height from finish ground, 2.00m crown diameter) within the construction site should preferably be protected using tree guards of approved specification.
- Existing drainage patterns through or into any preservation area should not be modified unless specifically directed by the Landscape Architect / Architect/ Engineer-in-charge.
- Existing grades should be maintained around existing vegetation and lowering or raising the levels around the vegetation is not allowed unless specifically directed by the Landscape Architect / Architect / Engineer-in-charge.
- Maintenance activities should be performed as needed to ensure that the vegetation remains healthy.

- The preserved vegetated area should be inspected by the Landscape Architect / Architect / Engineer-in-charge at regular intervals so that they remain undisturbed. The date of inspection, type of maintenance or restorative action followed should be recorded in the logbook. Or any alternative arrangements should be suggested by the respective municipal authority/ Dzongkhag

Recommendations for planting design considerations:

Plant materials are a very important component of landscape design, and planting design is integral to the landscape plan. Designing with plants requires awareness and knowledge of a broad range of aspects including (a) Ecology (b) Botany (c) Horticulture (d) Aesthetic Value (e) Growth and Survival and (f) Use of Plants to fulfil environmental design functions.

Plant material

The major sets of factors that influence the choice of plant material are related to the characteristics, both botanical and physical of plant material and the context in which the plant material is to be used. The inter-relationship of these sets of factors is the basis for developing a sound approach to the process of designing with plants.

Physical and Botanical Characteristics of Plant Material

The information on plant material should be available in a systematic format to include definition, significance and design implications of the following aspects:

- Nomenclature, Latin and common
- Origin, family, natural habitat
- Growth characteristic, form as a function of habit
- Physical characteristics, e.g. bark texture, foliage etc.
- Propagation and maintenance
- Use in Landscape Design

Vegetation Types: Evergreen and deciduous:

Some examples of the functional implications of using evergreen and deciduous plant material for specific situations are:

- Evergreen trees for:
 - i. places requiring shade throughout the year
 - ii. strong visual screening

- iii. part of windbreak or shelter planting
- iv. areas where leaf litter is to be discouraged
- Deciduous trees for:
 - i. greater visual variety
 - ii. partial visual barrier
 - iii. areas where under-planting is to be encouraged (e.g. grass)
 - iv. emphasis on branching and flowering pattern.
 - v. areas where shade is not required throughout the year.

Growth rate and age of the vegetation: Growth rate is directly related to the life-span of a tree and slower growing trees have a life-span extending to hundreds of years. The fast growing trees to the exclusion of other slower growing varieties is not recommended. Landscapes are developed to sustain future generations; slow growing & native trees must be included in all major planting schemes, especially those related to institutional campuses and large urban development. However, fast growing species do have a limited role, and are appropriate in situations where:

- Quick effects are required-for instance in windbreaks and shelterbelts.
- Immediate results with regards to stabilization of soil etc. are necessary as for instance in soil conservation schemes.
- As ‘nurse plants’ to protect slower growing sensitive species when necessary.

The slower growing species would generally be appropriate in situations where sustained environmental benefits are required such as roadside planting, campuses, townships, industrial areas, and other public landscapes.

Maintenance: The success of a designed landscape depends upon the growth of vegetation over an extended period of time; therefore maintenance of landscape is also a design component. Maintenance needs and a practice in any given situation arises out of the inter-relationship between the growth requirements of plant material chosen and the environmental conditions existing on site.

The likely degree of maintenance should be assessed based on the following:

- i. Scale of the Design Project
- ii. Financial and manpower resource
- iii. Availability of manures

- iv. Future intensity of site
- v. Environmental conditions

In small-scale projects such as gardens and small parks the natural environmental conditions can be changed and maintained in this changed state by management practices such as irrigation and application of fertilisers. The choice of plant species is therefore not very strictly limited by the existing environmental conditions. On larger scale schemes, such as very large parks, campuses and settlements, this kind of intensive maintenance is not possible, and any planting scheme, which does not take this into consideration, fail. The process of choosing plants must therefore respond to the existing environmental conditions and also in such cases the choice of plant material is restricted by these conditions and suitable species are limited. The type of treatment adopted also serves as a guide to the degree of maintenance required:

Table 4: Degree of maintenance required (for vegetation)

a)	Low Maintenance	The lowest degree of maintenance is usually possible in areas treated with native species of trees only. A slightly higher degree is necessary where native shrubs are also used, as these may require pruning
b)	Medium	Areas treated with a mixture of native and exotic trees Exotic shrubs and trees
c)	High	Exotic shrubs and ground covers Lawns and maintained grass areas Annual flowers, special schemes

Guideline 1.9: System approach adoption while land use plan/sub-division layout

All new settlements, residential colony, large campuses, etc., should follow a system approach while doing the land use plan.

Understanding of the *formative systems* while doing land use planning/ sub-division layout is important yet often ignored. For this, understanding the physiographic (natural) character of a site is the key.

Predevelopment performance or mimicking the natural performance of the site while doing any land use plan is extremely important. This becomes more significant in the case of Bhutan as the entire country is eco-sensitive. For instance, if the site discharged no overland flows into surface channels before development, then it should not release surface runoff (stormwater) into natural channels after development. Or take another example of a site which is (say) a conveyance zone in a watershed area where maintaining the continuity of flow even after development is important from sustainability perspective and long-medium terms ill consequences.

Guideline 1.10: Visual Quality

These guidelines aim at protecting and conserving the natural character of the hills and also to maintain key scenic views including heritage sites.

1. Protection of Ridgelines

A ridgeline is defined as the continuous line demarcating the contrast between the sky and the earth (i.e., the ground surface or top of tree line).

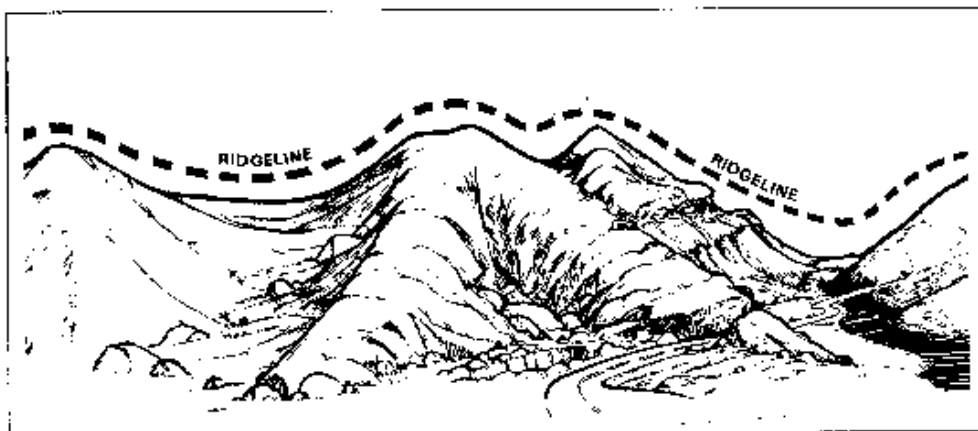


Figure 7: A Ridgeline

(Source: [http:// www.cavalrypilot.com/ fm21-26/ Ch10.htm](http://www.cavalrypilot.com/fm21-26/Ch10.htm))

Ridgelines should be protected to maintain the characteristic visual quality of a place. Following is recommended to achieve the same:

- Site building envelopes below the ridgeline and retain trees and other vegetation on ridgelines as much as possible. Roads or large and continuous buildings should not be located on or over ridgelines with an overall aim that the ridgeline is seen as a continuous line of natural terrain or vegetation.
- In case of gaps in the ridgeline caused by site development (e.g., roads, utility poles, buildings, etc.) plant trees and vegetation in front of and behind the disturbance to restore a naturally appearing ridgeline.

2. Scenic features including heritage sites

Scenic features hereby meant are features visually unique and visible to the community including buildings/ sites of heritage.

- Site/ plot should be designed so as not to alter or disturb any natural scenic features such as cliff, overhang, ridgeline, gully, water body, streams, etc.
- Apart from maintaining the traditional architectural style (as integrated in the development control regulations and building rules), it is strongly recommended to maintain such finishes and exterior colours which are complementary to the scenic feature, through the use of muted colours and natural materials.³

As seen in the figures below, use of vibrant exterior colour for walls and high reflective roofs is not desirable for visual quality.

- Location of buildings should be such as to not hamper the view of heritage sites/ buildings. The architectural exterior view of all buildings in heritage villages should be in harmony with the cultural and architectural view of the place.

³ During the site visit conducted by the authors, few new residential projects of startling colors (non harmonious with the natural terrain) were seen in and around Thimphu and need to be strictly controlled and restored.



Figure 8 : Use of various colours as part of the external finish



Figure 9: High reflective roofs of new buildings v/ s green/ ochre roofs of old buildings

SECTION 2: ENERGY AND ENERGY SYSTEMS

The prime intent of the energy and energy systems guidelines is to enable reduction of energy consumed by buildings through appropriate site planning, climate responsive design of buildings, efficient lighting and space heating/ cooling. Integration of renewable energy for water heating and possible generation of electricity by renewables (non-grid, other than the hydro-power based) may also be explored given the key criterion of energy security issues of the country and to also further reduce the carbon emissions. Some of these guidelines proposed in this section are also being looked into more detailed manner at building scale by the ongoing work on “Development of Green Design Guidelines for Buildings”, Department of Engineering Services, Ministry of Works and Human Settlement.

Guideline 2.1: Architectural Planning & Design

The layout of buildings in a new settlement at neighbourhood scale or bigger scale must respond to the solar geometry and wind directions. Some of the considerations could be following:

Site selection

- Based on availability of sun shine duration during winter months of December to March, the site should preferably be selected on sunny side or southern slopes.

Table 5: Sunshine availability during winter months (Dec to Mar)

Areas	No of sunny days in Dec	No of sunny days in Jan	No of sunny days in Feb	No of sunny days in Mar
Gasa	25.93	26.24	23.87	26.96
Punakha	25.93	26.24	23.87	26.96
Wangdue	25.93	26.24	23.87	26.96
Bumthang	26.87	25.61	24.61	28.48
Lhuentse	26.22	26.56	24.78	27.69
Haa	25.93	26.24	23.87	26.96
Paro	25.93	26.24	23.87	26.96
Thimphu	25.93	26.24	23.87	26.96
Trongsa	26.87	25.61	24.61	28.48

Areas	No of sunny days in Dec	No of sunny days in Jan	No of sunny days in Feb	No of sunny days in Mar
Trashiyangtse	26.22	26.56	24.78	27.69
Mongar	26.22	26.56	24.78	27.69
Trashigang	26.22	26.56	24.78	27.69
Sirang	27.04	26.92	23.94	28.17
Samtse	26.87	25.61	24.61	28.48
Chukka	25.93	26.24	23.87	26.96
Dagana	25.93	26.24	23.87	26.96
Sarpang	27.04	26.92	23.94	28.17
Zemgang	26.87	25.61	24.61	28.48
Pemagatshel	26.87	25.61	24.61	28.48
Samdrupjonkhar	26.93	27.38	24.69	27.93

Source: <https://eosweb.larc.nasa.gov/sse/RETScreen/>

Orientation

- As far as possible, the longer axis of the building should be oriented east-west direction to trap maximum solar energy during winter months.

Building Spacing

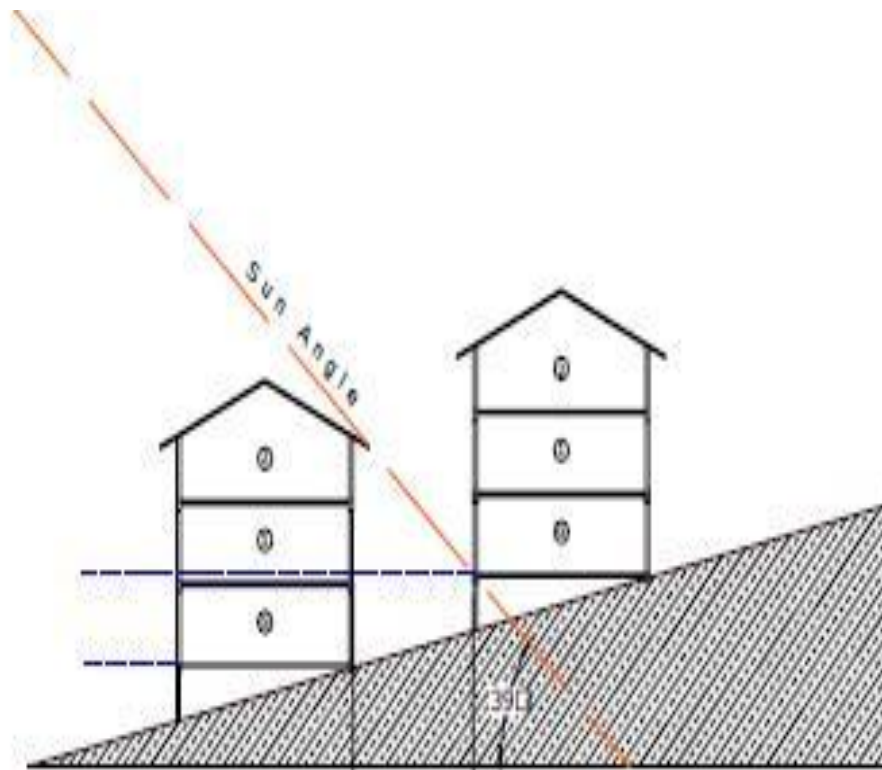
- Buildings should be spaced in such a way that they should not shade each other or block sun during winter. Minimum spacing for different types of housing for different cities of Bhutan are recommended in table below although given the terrain characteristics it is extremely difficult to follow these spacing in all conditions and regions;

Table 6: Minimum spacing between buildings

Zone 1				
Slope	Spacing (m)			
	G+1	G+2	G+3	G+4
1:20 (2.86 deg)	5.5	8.5	11.6	14.6
1:10(5.71 deg)	4.9	7.7	10.6	13.5
1:5(11.3 deg)	3.8	6.5	9	11.6
1:3(18.43 deg)	3	5.4	7.7	10
Zone 2				
Slope	Spacing (m)			
	G+1	G+2	G+3	G+4
1:20(2.86 deg)	5.4	8.4	11.5	14.5
1:10(5.71 deg)	4.8	7.6	10.5	13.4
1:5(11.3 deg)	3.7	6.4	8.9	11.5
1:3(18.43 deg)	2.9	5.3	7.6	9.9
Zone 3				
Slope	Spacing (m)			
	G+1	G+2	G+3	G+4
1:20(2.86 deg)	5.3	8.3	11.4	14.4
1:10(5.71 deg)	4.7	7.5	10.4	13.3
1:5(11.3 deg)	3.6	6.3	8.8	11.4
1:3(18.43 deg)	2.8	5.2	7.5	9.8

Zone 1		Zone 2		Zone 3	
1	Gasa	1	Haa	1	Tsirang
2	Punakha	2	Mongar	2	Samtse
3	Bumthang	3	Trashigang	3	Chukha
4	Lhuentse	4	Zhemgang	4	Dagana

Zone 1	Zone 2	Zone 3
5 Paro		5 Sarpang
6 Thimpu		6 Pemagatshel
7 Trongsa		7 Samdrup Jonkhar
8 Trashiyangtse		
9 Wangdue		



Minimum spacing between buildings based on the angle of sun on various slopes

Planning for spaces

- The living spaces of a building should be designed as day lit spaces.
- The non-living spaces i.e., stair cases, toilets, stores and garages may be planned preferably on northern side to provide as buffer to reduce heat loss from living spaces.
- North façade should have minimum door and window openings.
- Southern façade should have maximum glazing in order to capture maximum solar heat during winters.
- It is recommended that for new construction glazing should be in proportion to total surface area of the wall and preferably not exceed more than 50% in mid-altitude region i.e. 1500 m to 2200 m and not more than 70% in high altitude regions i.e. 2200 m and higher.
- In warm and humid climate regions (Southern part of the country), high level of cross ventilation is required in the buildings to maintain the thermal comfort. Small size windows should be placed on windward side, while larger windows should be placed on leeward side for facilitating direct ventilation through pressure difference.

Integrating solar heating systems in building designs

- Passive solar heating systems like solar air heating, water heating, sun space, solar walls, space heating green houses and solar trombe wall etc. shall be integrated in the building design wherever possible on southern side, so as to allow maximum direct solar access to these systems.
- The suitability of space heating systems to be installed or incorporated in the design of a solar passive building to be decided by the Architect/ Engineer/ Designer/ Solar expert in accordance with building site, climate and space heating requirements.

Provision of thermal barrier to reduce heat loss

- Preference must be given to use local materials i.e. stone, slate and mud and such construction practices to reduce heat loss and maintain adequate thermal comfort during peak winter months.

Wall and roofs

- For all buildings with active (mechanized) systems of space heating, walls and roofs should preferably be insulated by adequate insulation materials to provide

better thermal barrier outer and inner environments to reduce heat loss and maintain good thermal comfort.

- For other building types (passive buildings), roofs may be adequately insulated , cavity walls with air or with insulation may be provided

Air leakages

Proper sealing of all fenestrations (doors and windows) to the extent possible is recommended to reduce heat loss.

Guideline 2.2: Renewable Energy Systems

These guidelines on solar hot water and solar photovoltaic system are in addition to the guidelines being proposed by the Department of Renewable Energy which is working on implementation of renewable energy systems in the country. The guidelines proposed by the Department of Renewable Energy shall prevail over the guidelines proposed in this section. The section has been proposed to maintain the integrated approach of sustainable settlements.

Solar hot water system

- It is recommended to provide solar hot water system in all types of new commercial, hospitality, health, institutional and residential buildings.
- The capacity of the solar hot water system should be determined as per the requirement of particular building type.
- In residential and light commercial buildings solar hot water system should be integrated preferably in roof of the building, wherever possible so that the panel become the integrated part of the roof.
- In case of new commercial, health, hospitality and institutional buildings, it is recommended to have open space on the rooftop which receives direct sun light. The load bearing capacity of the roof shall be at least 50 kg/ m². All buildings of these categories must complete installation of solar hot water system before these get occupied.
- All the solar hot water heating systems should be equipped with automatic electric power back up so that same may be functional during cloudy or low sunshine days.
- Provision in the building design itself should be kept for an insulated pipeline from the rooftop in the building to various distribution points where hot water is required.
- The installation of solar hot water system should be as per the accepted domestic or international standards.

Table 7: Solar hot water generating potential avg. lpd/m²

Areas	Latitude	Longitude	Lpd/m ² by Glazed type collectors	Lpd/m ² by evacuated type collectors
Gasa	27.55	89.41	50	46
Punakha	27.61	89.86	50	46
Wangdue	27.46	89.9	50	46
Bumthang	27.6	90.81	45	46
Lhuentse	27.66	91.18	43	46
Haa	27.38	89.27	50	46
Paro	27.43	89.41	50	46
Thimphu	27.48	89.63	50	46
Trongsa	27.51	90.5	45	46
Trashiyangtse	27.35	91.27	43	46
Mongar	27.26	91.28	43	46
Trashigang	27.33	91.56	43	46
Sirang	26.96	90.11	42	46
Samtse	27.3	90.6	45	46
Chukka	27.05	89.56	50	46
Dagana	27.11	89.76	50	46
Sarpang	26.86	90.26	42	46
Zemgang	27.23	90.65	45	46
Pemagatshel	27.51	90.43	45	46
Samdrupjonkhar	26.81	91.56	48	46

Source: <https://eosweb.larc.nasa.gov/sse/RETScreen/>

Solar Photovoltaic Panel (SPV) for lighting

- It is recommended that the solar photovoltaic panels be integrated preferably in the building design for providing indoor lighting and emergency lighting.
- Stand-alone solar PV lighting along with electric back up may be provided for outdoor lighting applications i.e. street lighting and common area lighting.

Table 8 : Electricity generation potential from SPV

Area	Latitude	Longitude	Avg. annual Power generation potential (kWh/m ² /yr.)
Gasa	27.55	89.41	1580
Punakha	27.61	89.86	1580
Wangdue	27.46	89.9	1580
Bumthang	27.6	90.81	1521
Lhuentse	27.66	91.18	1518
Haa	27.38	89.27	1580
Paro	27.43	89.41	1580
Thimphu	27.48	89.63	1580
Trongsa	27.51	90.5	1521
Trashiyangtse	27.35	91.27	1518
Mongar	27.26	91.28	1518
Trashigang	27.33	91.56	1518
Sirang	26.96	90.11	1488
Samtse	27.3	90.6	1521
Chukka	27.05	89.56	1580
Dagana	27.11	89.76	1580
Sarpang	26.86	90.26	1488
Zemgang	27.23	90.65	1521
Pemagatshel	27.51	90.43	1521
Samdrupjonkhar	26.81	91.56	1541

Source: <https://eosweb.larc.nasa.gov/sse/RETScreen/>

Guideline 2.3 : Electricity distribution network

1. These guidelines are in addition or supportive of the guidelines been proposed by Bhutan Power Corporation (BPC). The guidelines being proposed by BPC shall prevail over these guidelines. Also, due consideration should be made while laying HT cables that it should be far away from the human establishments to avoid any safety issues.

Transformers

- Higher the rating, higher will be the no load loss therefore it is recommended that correct rating of transformer shall be selected.
- Stand By transformer without load also consumes energy. It is better to share the load on two transformers rather than putting load on one transformer while keeping other as stand by.
- Losses are more, if transformer temperature is more.
- The maximum efficiency of the transformer should be designed at a loading in the range of 50 to 65% of its full load capacity. If the average load is 80% or more of the rated power, a bigger transformer or a second transformer may be considered because the short-circuit losses become a large portion of the total losses.

Cables

- Cables contribution is highest in the overall technical loss in a distribution network therefore they should be sized in such a way that their cable current rating ensure their suitability w.r.t maximum current.
- Cable length should be selected with minimum numbers of joints. Joints in cables not only increase the loss but also result in to frequent break downs.
- It is recommended to slightly oversize cable if length of cable is more.
- A good quality of cable termination is also recommended.
- The distribution network may be designed to ensure a voltage drop less than 3% at highest load conditions.

Switch Gears

- Switch gears contribute loss both due to heating and also may be due to their own consumptions. All the switch gear shall be appropriately sized and shall have good quality of termination and adequate capacity of terminals.
- Sparking at terminals not only increases chances of break down but also affects the technical loss. Design & specification should ensure no sparking.

Motors

- Motor horsepower ratings should not exceed 20% of the calculated maximum load.
- Motors should be energy efficient i.e. eff-1 or eff-2 types.

Instrumentations

- Instrumentations in network increases joints and contribute in to technical loss due to own consumptions. Duplication of instruments in network shall be avoided and it shall be installed in such a way that there should be only one instrument for current, PF and energy measurement
- The more number of instruments in network affect measurements by over burdening CTs and PTs of distribution elements. Installation of CT normally results in two joints. Therefore installation of CTs should be minimized and BUSH mounting CTs may be used.

Protection and other numerical relay

- They contribute to technical loss in the same way as instruments do. They should be included in the design in less number with few joints and of good quality to reduce their own consumption.

Power factor

- All electricity supplies exceeding 100 A, 3-phase should preferably maintain their power factor between 0.95 lag to unity at the point of connection
- As the technical loss is dependent upon flowing current, so it is important to ensure apparent current is equal to active current. The network should have APFC units to monitor and control power factor. This also helps in regulating voltage levels. However it should be ensured that capacitor bank is switched off, whenever load is switched off. APFC should be as near to load as possible.

Harmonics

- Presence of harmonics can increase technical loss, can cause heating, can increase neutral current, can affect measurements and lastly can reduce efficiency of

devices. Feeders where load generates harmonics shall be isolated, so that it does not affect other load. If same is not possible harmonics filters should be installed.

Neutral current

- Neutral current and Neutral to Earth voltage are also useful and informative health parameters. By monitoring the same and ensuring them as low as possible, low losses is ensured.

Voltage drop

- Higher the voltage drop between voltage feeding point and at load point indicates high level of technical loss and it shall not be more than 3%.

SECTION 3: ENERGY EFFICIENT STREET LIGHTING

Street lighting is a very important element in settlements and consumes a lot of energy. Because of this large investment in energy use, methods for designing optimised systems using efficient lighting equipment and controls while maintaining aesthetically pleasing installation would not only provide energy efficiency benefits, but also provide potential economic benefits by increased commercial activity due to properly lit and safe circulation in settlements.

Often, planners and engineers do not appreciate opportunities for effective energy efficient street lighting from energy savings and a high quality design and performance perspective.

Guidelines for efficient street lighting integrate technical, performance and design guidance for effective energy efficient street lighting systems. The guidelines provide energy standards to ensure energy efficiency at the design of street lighting system and offer specific technical & design information to designers & engineers. In addition to this, these guidelines can also be used:

- To communicate the benefits of effective energy efficient street lighting to decision makers
- To understand the important elements and issues of effective energy efficient street lighting, and gain the knowledge to make informed street lighting procurement decisions

Energy efficient street lighting principles

At present, most of the street lighting is selected based solely on providing a recommended amount of light to the streets as per accepted standards using general types of poles and fixtures. Effective energy efficient street lighting design integrates efficient lamp technologies, optimum pole placement, efficient fixture photo metrics (light distribution), and aesthetics while using the least amount of energy and meeting various requirements for visibility & appropriate light levels.

Energy efficient street lighting opportunities and benefits

New effective energy efficient street lighting offer the greatest opportunities given that efficient designs and technologies can easily be integrated in to the plan.

Effective energy efficient street lighting installations offer the following benefits to large development. These opportunities and benefits need to be understood by the electrical consultant & landscape architect to help develop a holistic approach to street lighting design for settlements.

- i. Energy Savings-Through use of efficient technologies and design practices, excess energy use can be avoided.
- ii. Capital cost savings-Using the proper spacing and placement can reduce capital costs because more efficient systems can use fewer poles and fixtures.
- iii. Maintenance cost savings-Using lamps with longer lives and layouts with proper spacing and placement means reduced costs for fixing burnouts and paintings or replacing damaged poles.
- iv. Improved sense of security-Selection of efficient equipment and incorporating proper design can make an area appear safer and more secure without increasing light levels. In fact, light levels which are too high will not make an area seem safer. Direct glare and high light levels reduce perceptions of safety making visibility more difficult. Attention to uniformity described as even light distribution on the horizontal surface and light distribution on the vertical surface add to a person's sense of security.
- v. Evenly lit roads and walkways-Good design improves visibility by avoiding overly bright and dark patches on roads and walkways.
- vi. Reduce glare and improved visibility-Overly high light levels create unwanted glare that decreases visibility. Careful selection of fixtures and lamps that enhances visibility and improves detection of pedestrians by drivers and increases seeing distances beyond those provided by automotive headlights alone.
- vii. Economic development-Communities see street lighting as an important part of improving economic development efforts in all settlements.

Guideline 3.1: Energy efficient street lighting

It is recommended to introduce energy efficient street lighting for all new and (if possible) existing settlements. Following steps are recommended to be followed to achieve the above:

- Identification of road type : Roads classification should follow the Urban Roads Standards, 2002 or any other relevant document by the Royal Government of Bhutan superseding the same.
- Lighting level requirements: All the roads should be designed to meet the minimum illumination levels & uniformity coefficient.
- Energy standards: Lighting power per meter run of the road (W/ meter) for main traffic roads should be defined specifically for Bhutan

- Design basics & lighting system arrangements
- lamp selection
- Luminaire selection
- Controls

1. Identification of road type:

Road Classification and ROW	Max. no. of Lanes	Carriageway	Footpath, Drain, Shoulder & Median	Minimum Widths
<i>Primary:</i>				
Minimum– 15 m	4	12.00 m	3.00 m	Footpath
Ideal – 18 m	4	13.20 m	4.80 m	= 1.20 m
<i>Secondary:</i>				Drain
Minimum– 10 m	2	6.00 m	4.00 m	= 0.30 m
Ideal – 12 m	2	6.60 m	5.40 m	Shoulder
<i>Access:</i>				= 0.50 m
Minimum – 6 m	1	3.50 m	2.50 m	Median
Ideal – 8 m	1	3.50 m	4.50 m	= 0.25 m

Source: Urban Roads Standards, 2002

2. Illumination levels

All the lighting for different types of streets shall be designed to meet the minimum level of illumination levels & uniformity coefficient as follows:

- Primary Roads: Average lighting level on the surface of the road shall be maintained around 30 lux. Uniformity coefficient defined as ratio of minimum lighting level to average lighting level shall not be less than 0.4.

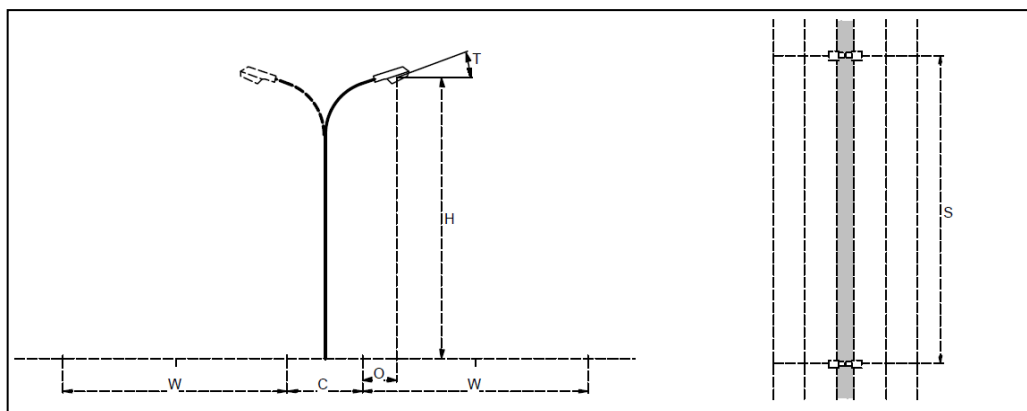
- Secondary Roads: Average lighting level on the surface of the road shall be maintained around 15 lux. Uniformity coefficient shall not be less than 0.4.
- Access Roads: Average lighting level on the surface of the road shall be maintained around 10 lux. Uniformity coefficient shall not be less than 0.4.

Lighting level measurement

- Lighting levels shall be calculated or measured at a grid of not more than 1M*1M on road surface between one spacing of street lighting system. The illumination level on the street will be the average of all these lighting levels and uniformity coefficient will be calculated by dividing minimum lighting level by illumination level of the street.

3. Design Basics

- (i) Mounting height (H)- The vertical distance between the centre of the luminaire and the surface of the carriageway measured vertically is called the mounting height of lighting installation. The optimum mounting height should be chosen by taking into account the light output of the sources, the light distribution of luminaries, and the geometry of installation. Table below shows the recommended mounting heights for different category of roads and carriageway width.
- (ii) Spacing (S)- The distance, measured horizontally, along the centre line of the carriageway, between successive luminaries in an installation is defined as spacing of lighting schemes.
- (iii) Carriageway-That portion of a highway intended primarily for vehicular traffic.



- (iv) Dual carriageway-Dual carriage is defined as a layout of two separated carriageways, each reserved for traffic in one direction only.
- (v) Carriageway width (W)- The distance between kerb lines measured at right angles to the length of the carriageway is width of carriageway.
- (vi) Overhang (O)- The distance measured horizontally between the centre of a luminaire mounted on a bracket and the adjacent edge of the carriageway is defined as overhang.
- (vii) Span- That part of the highway lying between successive luminaries in an installation is termed as span
- (viii) Central verge-Central reserve is a longitudinal space dividing a dual carriageway.
- (ix) Verge-Unpaved area flanking a carriageway, forming part of the highway and substantially at the same level as the carriageway is called verge.
- (x) Kerb-Kerb is formed at the edge of a carriageway with the help of border of stone, concrete or other rigid material.

Types of Arrangement in street lighting

Four fundamental types of arrangement are considered in road lighting design:

Single side arrangement

In single-side arrangement, all the luminaries are on one side of the carriage-way. It is recommended for small road width.

Staggered arrangement

In staggered type arrangement, the luminaries are situated on either side of the carriage-way and may be employed when the width of the carriage-way is of medium size.

Opposite

In opposite arrangement, the luminaries situated on either side of the carriage-way opposite to one another is advisable when the width of the carriage-way is big.

Axial or twin central

In axial arrangement, the luminaries are placed along with axis is usually considered for major roads.

Other arrangements exist, but they result from the combination of the four preceding fundamental types.

4. Street lighting system

Based on their performance, the lighting components can be grouped in three systems.

Structural system

- Poles & pole foundation or base

Optical system

- Luminaires

Electrical system

- Lamps, ballasts, and service cabinet or fuse box

Lamps

- Street lighting systems generally use three types of high intensity discharge (HID) lamps. They are high pressure sodium vapour (HPSV) lamps, metal halide (MH) lamps, and high pressure mercury discharge (HPMV) lamps.
- HPSV lamps produce yellowish light; have very high efficiency, high lumen maintenance, very long life but very poor colour rendition.
- MH lamps are also having high efficiency and very good colour rendering and being recommended for new installation but they tend to have a shorter life and poor lumen maintenance.
- HPMV lamps are not very frequently used in street lighting now. They are least energy efficient among HID lamps but they have colour rendition better than HPSV lamps.
- Light-emitting diode (LED) technology is a fast developing one with significant energy saving potential and very long life. They do not use ballasts or starters and have excellent colour rendering quality, however, their upfront cost is quite high as compared to HID lighting systems.

150 W, 250 W & 400 W High pressure lamps

- Luminous efficacy of lamps should be in the range of 110 ~ 130 lumen/ watt.
- Lamps should have fast ignition time which should be less than 180 seconds.
- Lamps should have high maintenance of 95% at the end of 15000 hrs.
- Lamp life at 50% mortality should be more than 30,000 hrs.

250 W Quartz metal halide lamps

- The luminous efficacy of the lamp should be more than 76 (lumen/ watt).
- These lamps should function at a minimum supply voltage of 198 volts and the CRI should be more than 80.
- It should be possible to operate these lamps both with electronic as well as electromagnetic ballasts.

Ceramic discharge metal halide lamps

- Its luminous efficacy should be more than 93 (lumen/ watt).
- The compact single/ double ended 150 W with CRI more than 80 should function with electromagnetic and electronic ballast.

150 W, 250 W Ceramic discharge metal halide lamps

- The luminous efficacy of these lamps should be more than 93 lumens per watt.
- They should operate even at a low supply voltage of 198 volts and have CRI more than 80 and Correlated colour temperature (CCT) which defines the light colour of 4200 K.

Ballasts & Igniters

Ballasts are required for all HID lamps. They provide proper open circuit voltage to start the lamp, keep the lamp operating within the desired parameters and help adapt lamps to any one of the line voltages commonly available. But because of their configurations they tend to have power loss.

- Ballasts & igniters should conform to Bhutanese standards, if available.
- Power delivery to lamp should be more than 95%.
- Ballasts should be vacuum impregnated open construction type.
- Ballasts should be low loss ballasts and the power loss in HID fixtures should not be more than as specified below.
 - 150 W - <18 Watts
 - 250 W - < 24 Watts
 - 400 W - < 44 Watts

Luminaires

The luminaire has a double role of protecting the light source from the weather and redistributing its luminous flux.

In the choice of the luminaire, following points should be considered:

- Nature and power of the source or source
- Nature of the optical arrangements and the light distribution which they provide
- Light output ratio
- Whether the luminaire is open or closed type
- Resistance to heat, soiling and corrosion
- Protection against collection of dust and insects
- Resistance to atmospheric conditions
- Ease of installation and maintenance
- Presence or absence of auxiliaries and
- Fixing arrangements, the weight and area exposed to wind pressure



The influence of all these factors varies according to local circumstances, and it is difficult to recommend one solution or each type of lighting installation.

However, one essential characteristic of luminaires the choice of which directly influences and quality of the lighting. That is, the general form of its distribution curves of luminous intensity particularly in directions near the usual directions of vision. Three fundamental forms of light distribution are considered according to the degree of glare which is acceptable:

- Cut-off luminaires,
- Semi-cut-off luminaires, and
- Non-cut-off luminaires

Cut-off luminaire

A luminaire whose light distribution is characterized by a rapid reduction of luminous intensity in the region between 800 and horizontal 900. The intensity at the horizontal should not exceed 10 cd per 1000 lm of flux from the light sources and the intensity at 800 is of the order of 30 cd per 1000 lm. The direction of the maximum intensity may vary but should be below 650.



The principal advantage of the cut-off system is the reduction of glare and its use is favoured under the following conditions:

- Matt carriageway surfaces
- Absence of buildings
- Presence of large trees
- Long straight sections
- Slight humps, bridges, and
- Few intersections and obstructions

Semi-cut-off luminaire

A luminaire whose light distribution is characterized by a less severe reduction in the intensity in the region 800 to 900.

The intensity at the horizontal should not exceed 50 cd per 1000 lm of flux from the light sources and the intensity at 800 is of the order of 100 cd per 1000 lm. The direction of the maximum intensity may vary but should be below 750. The principal advantage of the semi-cut-off system is a greater flexibility in siting, and its use is favoured under the following conditions:



- Smooth carriageway surfaces
- Buildings close to carriageway, especially those of architectural interest and
- Many intersections and obstructions

Non-cut-off luminaire

A luminaire whose luminous intensity in directions making an angle equal to or greater than 80° from the downward vertical is not reduced materially and the intensity of which at the horizontal may exceed the values specified for the semi-cut-off distribution, but should not nevertheless exceed 1000 cd. Non – cut-off luminaires are permissible only when a certain amount of glare may be accepted and when the luminaires are of large size and of reduced brightness. In certain cases they have some advantages in increasing the illumination on facades.



5. Street lighting system controls

In Bhutan, the streetlights are switched on and off manually. No automatic controls are currently being used. Manual systems often lead to energy wastage due to various reasons. Therefore, it is recommended that automatic lighting controls sensitive to the seasonal variation and adjusts on & off time based on actual length of day/ night may be used for new settlements and/ or existing settlements.

- Automatic controls are provided for all the road lighting to automatically respond to seasonal variation of sun set & sun rise timings

(i) Microcontroller Time Switches

Microcontroller based timeswitch, which has inputs like Real time, Date, Month, Year, plus and minus offset is one such device which could be used. It can be set through available tactile switches and with help of seven-segment display.



Memory of the unit has date wise yearly sunset and sunrise timings for the required city, as the date advances output relay gets ON as per the concurrent Sunset and Sunrise Timings. In case if it is required to change this timing, it can be done with help of plus and minus offset. Micro controller's RTC has got 5 years backup through battery; hence the set program remains intact even in power failure condition. Enough precautions for line supply surge are taken. The Output channel relay operates the electrical contactor that ultimately controls the lamp load. Due to its versatile concept of switching at Sunset and Sunrise Timings throughout year, it gives saving in electrical units, which ultimately result in, reduced electric bills.

(ii) Passive infrared sensor operated Switches

These devices sense the radiations equivalent to allowable light levels and switch on and off the fixtures at dusk & dawn.

- In order to further conserve energy, it is recommended that street lighting systems are equipped with proper device to be dimmed to 50% of total light output after mid night when there is no or very less traffic on the road

Dimming of street lighting is possible with the help of new types of fixtures which are now equipped with change over or multi-tap ballasts. Instead of one, fixtures are fitted with two ballasts and same lamp can operate at two different wattages at set change over time which can be set with a timer. Power/ time switch an auto dim device which can perform auto dimming. At mid night when traffic gets thin auto dim can change over from higher wattage ballast to lower wattage ballast.



Typical installation w/ o dimming



Typical installation with dimming



Figure 10: Visual impact of streets with and without dimming

Electrical system

- Electrical distribution for road lighting should be designed to maintain a power factor more than 0.95 lag and a voltage fluctuation of not more than 5% throughout the year

Energy monitoring

- A dedicated feeder should be provided for street lighting. Electronic energy meters should be installed to record the consumption in the street lighting system.

Green Power

- 15% (or any graded limits may be set in association with the Department of RE) of the connected street lighting load may be catered through RE power with grid backup. This can be provided either through standalone solar lighting system or centralised RE power system.

SECTION 4: WATER & WASTE WATER MANAGEMENT SYSTEMS

Bhutan is well endowed with rich perennial water resources due to its head water source being fed with permanent glaciers and associated glacier lakes, vast forest coverage & good monsoon. There are four major river basins in the form of Amochhu, Wangchhu, Punatsangchhu & Manas. Of the entire population, 98% urban and 88% rural population has access to safe drinking water however, localized pollution of surface water sources in urban areas and seasonal shortages of water in some season is reported.

Due to increasing urbanization, increasing water demand for various applications and climate change implications following challenges have been recognized:

- Unpredictable seasonality
- Accelerated melting of glaciers
- Extreme Climate events: Higher incidence of flooding and dry spells
- Reduction in overall river flows and water shortages
- Drying of water sources and rivers
- Increasing demand from increasing populations and lifestyle changes
- Unsustainable development of hydropower
- Extinction of plant and animal species
- Glacier lake outbursts

As a result, one of the prime requirements for buildings and settlements is to adopt water sensitive urban design, rain water harvesting at individual building and neighbourhood scales, proper management of surface water sources, control on the spread of impervious ground cover which impedes the natural recharging of ground water sources and adds to the urban heat island effect. The approach for preparing the guidelines under this section is illustrated in the adjoining figures.

Guidelines proposed in this section are in addition/ support of the existing measures being taken up by the Divisions of Urban Infrastructure and Rural Infrastructure Services.

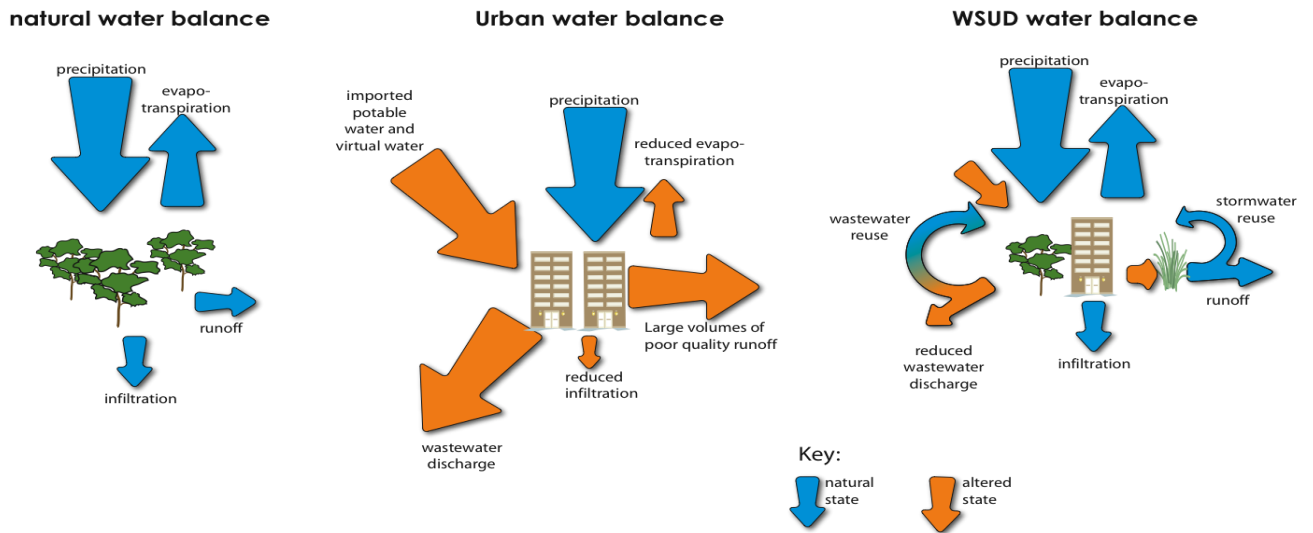


Figure 11 : Water Sensitive Urban Design v/ s conventional urban water use (Source: Prof. Rob Skinner, Monash University, Australia)

Downpipe dis

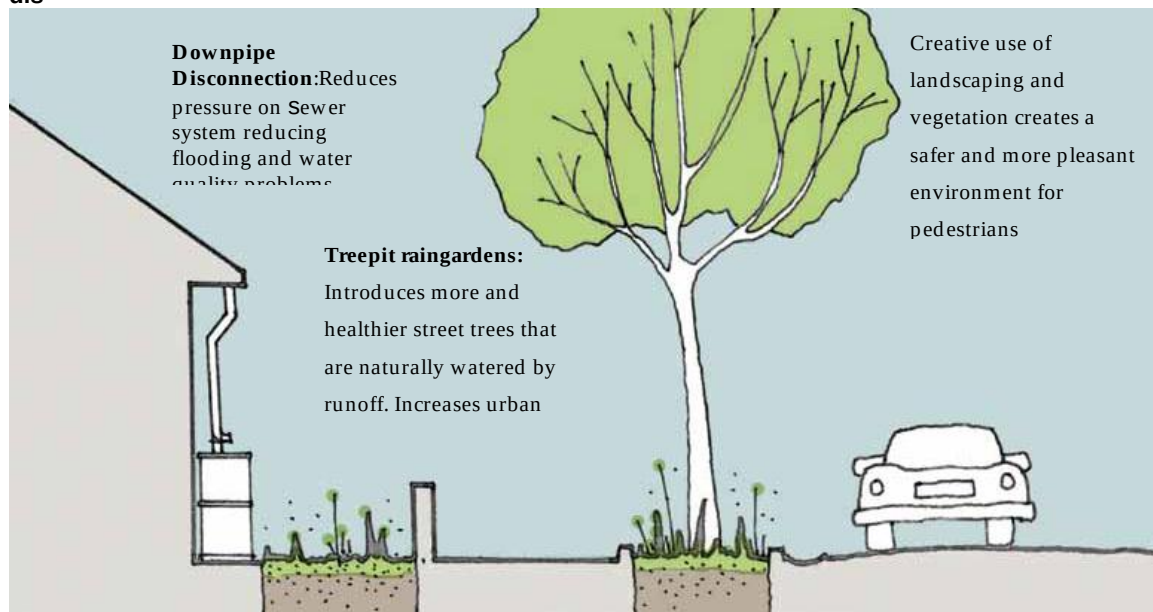


Figure 12: What could a water sensitive design do at neighbourhood scale? (Source: CIRIA, 2013, Water sensitive urban design in the U.K)

Guideline 4.1: Sustainable water management

Guideline 4.1.1

All settlements (urban and rural) should have provision for adequate quality of water for potable and non-potable applications and to ensure the above, a stringent monitoring plan should be adopted through periodic audits.

Why it is required?

The quality of water, whether it is used for drinking, irrigation, or recreational purposes, is significant for health worldwide. The quality of drinking-water is a powerful environmental determinant of health. Assurance of drinking-water safety is a foundation for the prevention and control of waterborne diseases. In case treated wastewater is used for any applications(non-potable), it should meet the quality standards specified for those applications. Maintaining the quality of drinking water helps to ensure safe drinking water to the consumer.

To ensure safe drinking water, both municipal and/ or harvested rainwater has to be treated before use to varying levels depending on the water quality of the source.

Choosing a Water Treatment system based on Common Contaminants

In order to ensure safe drinking water, it needs to be treated before use. Treated water is that which has gone through the treatment process for removing contaminants like bacteria and other constituents as per Drinking Water Standards of Bhutan.

The table below lists out the various treatment systems that could be used for each type of contaminant.

Table 9 : Water treatment methods based on contaminants

	Contaminant	Treatment methods
Physical Parameter	Turbidity/ Transparency	Slow sand filter
		Candle filter
		Cloth filtration
		Coagulation
		Sedimentation

Guidelines for Planning and Development of Human Settlements in Urban and Rural Areas of Bhutan to minimise environmental impacts

	Contaminant	Treatment methods
Chemical Parameter	Odour	Aeration/ Oxidation
		Activated carbon filter
		Charcoal
		Resin
		Boiling
	Colour	Charcoal
		Activated carbon filter
		Slow sand filter
		Resins
	Fluoride	Activated Alumina
		Nalgonda
	Nitrate	Reverse Osmosis
		Ion Exchange
		Distillation
	Ammonia	Chlorine
		Boiling
	Iron	Oxidation and Settling
		Boiling
	Hardness	Boiling and settling/ Filtration
		Reverse Osmosis
		Resin
		Ion Exchange water softeners
	Chloride/ Free chlorine	Reverse Osmosis

Contaminant	Treatment methods
Bacterial Contamination	Activated carbon filter
	Slow sand filtration
	Boiling
	Chlorination
	U V Radiation
	Resins
	Ozonation

Source: 2009, TERI and TVPL, Environmental Building Guidelines for Hyderabad Metropolitan Area, HMDA.

However, integration of a purification techniques and the type of technology to be used will depend on several factors:

1. Kind of contaminant
2. Extent of contamination
3. Simple & durable
4. Low maintenance
5. Dependency on power
6. Profile of the water users
7. Affordability

Often, in spite of precautions, contamination of water can occur during its storage or transportation to the point of consumption. Hence storage and maintenance of treated water is as essential as is the purification process.

Principles of Water Purification

All the water treatment technologies essentially follow three main principles of primary purification. Ideally all the three principles should be followed rigidly in the same order. One cannot omit or substitute any principle. All principles must be followed to get a good quality safe drinking water

1. Sedimentation
2. Filtration
3. Disinfection.

Primary Treatment

1. Sedimentation

Sedimentation is a process whereby suspended matters in water settle down and which can be separated by straining. It also means storage of water. Physical and chemical events take place during sedimentation.

a. Physical - Quality of water improves by merely storing it. About 90% of the suspended and colloidal impurities settle down within 24 hours by gravity. The water becomes cleaner and allows penetration of sunlight, initiating a further purification process. Settled suspended particles are seen at the bottom. For successful sedimentation, water should not be disturbed during storage.

b. Chemical - Interaction between constituents also aids in purification. Certain lighter suspended particles may not settle quickly, or may not settle down at all. In that case coagulation is necessary. Alum can be used at home to facilitate settling of suspended impurities, to get clear water. This is mainly practiced in rainy seasons when the water is much more turbid. Use of coagulants helps to reduce color, odor and improve taste of the water.

2. Filtration

Filtration is the second stage of purification and is the most important step in purification. The process of passing the water through beds of fine granular materials (called filters) such as sand is known as filtration. Filtration helps in removing color, odor, turbidity and pathogenic bacteria.

The settled particles in water can be effectively removed by this process. There are three action involved in filtration:

- a. **Mechanical Straining:** The suspended particles present in water, which are of a bigger size than the size of the voids (empty spaces) in the sand layers of the filter, cannot pass through these voids and get arrested in them. The resultant water is free from suspended particles.
- b. **Sedimentation:** The voids between sand grains of filter act more or less like a tiny sedimentation/ coagulation tank. The impurities are adhered to the sand surface and slowly a gelatinous film or coating is developed on sand grains. Colloidal matter and bacteria present in water stick to this film. The impurities thus settle down in the voids and get removed.

- c. **Electrolytic changes:** The purifying action of the filter can also be explained by theory of ionisation.

According to this, a filter helps in purifying the water by changing the chemical characteristics of water. Sand grains of the filter media and the impurities in the water carry electrical charges of opposite nature. When they come in contact with each other, they neutralise each other, thereby changing the characteristics of water and making it purer.

3. Disinfection of Water

This treatment destroys harmful germs (bacteria, viruses, protozoa, etc.) by either killing them or making them inactive. Water can be disinfected by several means:

- Application of heat or other physical agents
- Surface active chemicals
- Resin (iodine based, e.g. Zero-B)
- Radiation by ultraviolet light and radioactive ions
- Alkalis and acids
- Metal ions like silver, copper, mercury.
- Oxidants with halogen, ozone other chemical compounds like potassium permanganate, bromine, iodine and chlorine. (*Ozone at 0.5 ppm takes about 5 minutes to kill bacteria. Chlorine at 1ppm takes about 2 hours and silver takes about 4 to 10 hours.*)

Local authorities commonly use chlorine, iodine and silver to kill bacteria. UV radiation and ozonation may also be used for large water supplies in townships/ resorts/ hotels located outside the municipal limits.

Secondary Treatment

There are several treatment methods that have been developed which are effective and can remove pollutants to desirable concentrations. Techniques have been devised according to the specific contaminants (Table). Generally the techniques adopted for water purification are based on aeration, precipitation, coagulation, filtration, demineralization, adsorption, ion exchange and membrane processes like reverse osmosis. The technologies like ion exchange and reverse osmosis are highly effective but expensive and are unable to reach the masses. Many other technologies have been developed which are less expensive like precipitation and coagulation. Though not as effective as the membrane utilising technologies, they are effective in removing specific contaminants like Fluoride, Arsenic etc at community and individual household level.

These Secondary level treatment technologies have been broadly classified on the principle of water purification:

1. Disinfection: UV radiation, Ozonation, Solar Disinfection
2. Filtration/ Demineralization: Ion Exchange, Activated Carbon Filtration,
3. Membrane Processes (Micro filtration, Nano filtration, Ultra filtration, Reverse Osmosis, Electrodialysis)

1. Disinfection

Ultra Violet radiation (UV):

UV is nature's way of purification. It is a band of invisible light in the electromagnetic spectrum. This range 200 nm -285 nm is the germicidal range. Proteins and nucleic acid, which all micro-organisms contain as their main constituents, absorb UV radiation energy. After absorption, the UV energy destroys or inactivates the DNA, thus preventing the microorganisms from reproducing. UV is also known to bring down Total Organic Carbon (TOC) considerably in water.

Precaution:

The water entering the UV unit must necessarily be clear as suspended solids provide a shielding effect to microorganisms. Hence Pre-treatment is necessary.

Ozonation:

Ozone is the strongest oxidising agent for water treatment. By virtue of its properties, ozone is also the strongest disinfectant.

Solar Disinfection:

A simple method of improving the quality of water with the help of sunlight. It employs use of solar UVA radiation and temperature to inactivate pathogens. The disinfection process is effective through a 2way process- exposure to UV-A radiation and increased water temperature. If the water temperature rises above 50°C, the disinfection process may take one hour.

2. Filtration/ Demineralization

Ion Exchange

Ion exchange is a process that includes two very similar applications of the same technology for removal of excess amounts of Hardness, Iron, Nitrates

Water softening

This is the process of removing ions from the water and replacing/ exchanging them with sodium ions and chloride ions. Ion Exchange water softeners employ the use of NaCl (sodium chloride) for a cation exchange process. Na or K replaces Ca, Mg, Fe, Mn etc in the water. The most common use for this is at household level.

Deionization:

Here, the hardness and other ions that are initially in the water are removed and replaced with H⁺ and OH⁻ ions, which can combine to form water. Hence, it reduces deposits and scale formation because of high level of hardness. This is used in applications where extremely pure water is required.

Activated Carbon Filtration

Activated carbon is extremely porous with a very large surface area. It employs a process called adsorption, in which molecules of the contaminants attach themselves to the surface of the carbon either by physical or chemical attraction.

The two main reasons that chemicals adsorb onto activated carbon are- a "dislike" for water, and attraction for the activated carbon.

3. Membrane Processes

Reverse Osmosis (RO), Nano Filtration (NF), Ultra Filtration (UF) and Micro Filtration (MF) are the commonly used pressure driven membrane processes in the order of increasing pore opening.

Membrane material

Cellulose acetate, Aromatic polyamide, nylon derivatives, Polyvinyl alcohol derivative etc. These membranes have a preferential attraction for water and rejection for charged ionic substances.

The filtration is dependent on the pore size, pore size distribution and pressure.

Micro Filtration

A very low-pressure (less than 1 Kg/ sq. cm) process which separates particles above 0.05 microns and below 1 micron from the solvent. MF membranes are primarily used to remove particulate matter and bacteria from water.

Ultra Filtration

This is a low pressure (less than 10 Kg/ sq. cm) separation process which allows low molecular solutes (>1000 MW) are retained. Ultra filtration membranes (1nm to 10nm)

are used to remove particulate, colloidal matter, bacteria, pyrogen and viruses from water.

Nano Filtration

This is a process in between ultra filtration and reverse osmosis. The NF allows monovalent salts like NaCl, CaCl₂ to pass through and retains divalent anionic salts like Na₂SO₄, MgSO₄ along with solutes having molecular weights greater than 300. NF membranes are often called a loose RO and are used as softening membranes or to remove dyes and organic compounds from water and liquid effluents.

Reverse Osmosis

Reverse Osmosis is a high pressure (15 Kg/ sq. cm); energy efficient separation process. Low organic salts are concentrated while water is allowed to pass. The pore size of 5-20AD of the membrane retains over 95-99% of the dissolved salts. In this process, water is forced through a semi-permeable membrane under pressure, because of which the dissolved salts are held back in discharge.

All dissolved salts, sugars, bacteria, viruses, pyrogens, proteins, dyes and other particles with a weight greater than 150-250 daltons can be removed by RO to the highest extent. It is also used to remove inorganic salts, TDS from brackish water, seawater and waste water. While ordinary filters can only remove suspended particles and sediments from water, RO can also remove high percentages of dissolved contaminants- molecule by molecule- from water.

Electrodialysis:

Electrodialysis units are normally used to desalinate brackish water. It involves the separation of dissolved cations and anions by the use of ion exchange membranes.

Electromembrane (electrodialysis)

Because of its low sensitivity towards impurities in water and simplicity of models, electrodialysis seems more attractive for small applications like homes, tourist cottages, hotels and yachts.

For large settlements, water should preferably be treated at a centralised level and then supplied to individual buildings. Precautions are recommended for storage and conveyance of the treated water to prevent any contaminants. Alternatively, water for potable application should be centrally treated to at least primary level and then supplied to individual buildings for further treatment and end-use application.

Guideline 4.1.2: Water quality standards for Flushing is recommended to be adopted to promote use of recycled wastewater

There are no Bhutanese Standards for using recycled water for flushing applications.

Reuse Standards and to some extent testing protocol exist in some countries of Europe and in US. Findings from a study done by the CMHC, Canada is presented in the following table.

Table 10: Recommended water reuse standards

Parameter	Units	Toilet flushing	
		Median*	Maximum
BOD	mg/ L	≤10	≤ 20
TSS	mg/ L	≤10	≤ 20
Turbidity	NTU	≤ 2 (alternative to TSS)	≤ 5 (alternative to TSS)
Fecal Coliforms	CFU/ 100 ml	< 1	≤ 200
E Coli	CFU/ 100 ml	< 1	≤ 200
CI residual	mg/ L	0.1 to 1.0 +	

*Medium based on data collected following the US EPA ETV testing protocol, or a minimum of five samples collected over a 30-day period.

Source: 2005, Research report on Water reuse standards and testing protocol, Healthy Housing and Community Series, CMHC, Canada

Whatever may be the reuse application, it is strongly recommended that cross-connection concerns be addressed by using an air gap between potable water supply for makeup water and reuse water storage. Also, guidelines prescribed in the International Green Plumbing Code or Uniform Plumbing Code of India may be referred and customized for Bhutan.

Guideline 4.1.3

To ensure adequate water monitoring and leak detection plan at the settlement level, occasional water audits or preferably regular monitoring through SCADA system (for large cities such as Thimphu) is recommended.

Water audits at settlement level must be taken at least once a year and the report must contain the following:

- Amount of municipal water available and total water utilized from both municipal water supply and other sources
- Water losses and efficiency of the system along with reasons for such losses
- Measures to check water losses and improve efficiency

In lieu of the increasing municipal water supply-demand gap in some parts of the country and when unaccounted for water is unknown, it becomes extremely important to have a strict monitoring plan. Regular water audits or real time based monitoring through SCADA system has the potential to save this loss of water.

Guidance Notes

What is a Water Audit?

Water audit determines the amount of water lost from a distribution system due to leakage and other reasons such as theft, unauthorised or illegal withdrawals from the systems and the cost of such losses to the utility. Comprehensive water audits give a detailed profile of the distribution system and water users, thereby facilitating easier and effective management of the resources with improved reliability.

Steps in a Water Audit

Step 1: The Water Use Inventory

It is important that facility manager/ owner/ user develop an understanding of exactly how and where their large development uses water. To do this, an inventory of all water use points in the site premises with flow rates must be developed. The complex may or may not have many typologies of buildings. Conduct sample audits of typical building types in the premises.

The inventory should also include the mechanical system installed (if water based), its location, its capacity, and the rate at which it uses water for cooling. In some cases, the owner's manual will identify the water flow rate. However, it may be necessary to use a stopwatch and a bucket to determine the actual water flow rate.

Step 2: Metering

Readings from water meters provide an indication of how a building compares to other buildings, but it will not show where to look for areas where water use can be reduced, particularly if the building is large or complex. Narrowing use down to possible areas where use can be reduced requires sub-metering.

Where and how sub-meters are installed depends to a great extent on the design of the water system serving the settlements/ campuses/ township. Ideally, meters and sub-meters would be installed on each building and respective floors of the building. Each

meter should be read at least monthly. All meter readings should be logged and reviewed on a regular basis for unexplained changes.

Tracking water meter readings provides a baseline of water use for the entire settlement. The key to gaining useful information from sub-meters is to have the meters read on a regular basis, and as frequently as possible. Frequent readings help to quickly identify and locate leaks.

Step 3: The Water Efficiency Plan

Once information has been gathered on how water is being used within the settlement, the report will give the water balance, places of leaks, leaking pipes, based on which an action plan can be established for reducing water use within the settlement. The plan may set specific water use reduction goals for the entire development depending on the residents/ occupants' desire and aspirations. Those goals must be measurable, achievable and realistic. The plan must also identify a mechanism for periodically reviewing the success of the program in meeting those goals. The water efficiency plan should set the priorities for implementation based on costs, benefits and available manpower.

SCADA for water and waste water management of large settlements

SCADA stands for Supervisory Control and Data Acquisition systems. SCADA is electronic and capable of automation from the basic level to a very high level of sophistication. As the name indicates, it is not a full control system, but rather focuses on the supervisory level. As such, it is a purely software package that is positioned on top of hardware to which it is interfaced, in general via Programmable Logic Controllers (PLCs), or other commercial hardware modules. SCADA are used for many applications including water supply, waste water treatment and management systems.

Many Indian city corporations have started using the system for managing water supply systems.

Advantages of SCADA to the user⁴

There are a number of advantages of SCADA for users. A few are:

- Water users do not have to manually read and record meter readings at regular intervals because data on water use is collected automatically;
- Data can be downloaded at the users convenience;

⁴ http://www.ecy.wa.gov/programs/wr/measuring/images/pdf/scada_systems.pdf

- Can be rigged for telemetry access by radio, satellite, cell phone, or telephone landline
- and allow the user to remotely control the entire supply system and access data instantly.

Guideline 4.2: Sustainable wastewater management

Guideline 4.2.1

- All new settlements should have provision of the Dual Plumbing/ Dual Water Distribution System to recycle and reuse the treated waste water.
- All large hotels and buildings which are water guzzlers should have mandatory provision of the dual plumbing system

Growing urbanization accelerates the situation of increasing water demands for domestic, industrial, commercial, and agricultural purposes. As water demands and environmental needs grow, water recycling will play a greater role in the overall water supply. By working together to overcome obstacles, water recycling, along with water conservation can help to conserve and sustainably manage vital water resources.

Water recycling is reusing treated wastewater for beneficial purposes such as agricultural irrigation, industrial processes, toilet flushing. The term water recycling is generally used synonymously with water reclamation and recycled water can satisfy most water demands, as long as it is adequately treated to ensure water quality appropriate for the use. As for any water source that is not properly treated, health problems could arise from drinking or being exposed to recycled water if it contains disease-causing organisms or other contaminants.

Water recycling is a sustainable approach and can be cost-effective in the long term, the treatment of wastewater for reuse and the installation of distribution systems can be initially expensive compared to such water supply alternatives as imported water. The additional cost of providing a dual system may add only 9-10% to the cost of plumbing.

Why is this required?

Water recycling and reuse is required due the following reasons:

- To facilitate a more forward-looking focus on water -starved areas of the country
- Help to stretch or increase water supplies, satisfy the demands of growing populations, protect environmental needs, and strengthen local economies.
- Minimize water crises all over the country.

- To reduce the load of water pollution.
- To reduce health hazards spread by water borne diseases.
- Provide a balanced, practical approach to water management.

Water recycling and reuse is beneficial as it eliminate dependence of developmental area on local water supply authority's upto a large extent. And also contribute towards more green and sustainable developmental activity as there is no discharge of waste effluents from the developmental area premises. The use of the treated effluent results in substantial savings in irrigation water costs and reduces the likelihood of water pollution, assuming that the effluents would otherwise have been disposed of treated/ untreated through STP's.

Reuse technology eliminates the need to use potable water supplied by the Municipal local authorities for irrigation and makes it available for other uses.

Guidance notes:

What is Dual water distribution system

As the name implies, dual distribution systems involve the use of water supplies from two different sources in two separate distribution networks. The two systems work independently of each other within the same service area. Dual distribution systems are usually used to supply potable water through one distribution network and non-potable water through the other. The systems would be used to augment public water supplies by providing treated waste water for purposes other than drinking. Such purposes could include fire-fighting, sanitary flushing, street cleaning, or irrigation of ornamental gardens or lawns.

Technical Description of the system

The systems are designed as two separate pipe networks: a potable water distribution system, and a system capable of distributing treated water from waste water treatment facility for non-potable water application. The system includes distribution pipes, valves, hydrants, standpipes, and a pumping system, if required. Pipes in the systems are generally cast iron or ductile iron, although other materials have also been used.

Pumps may be required to lift wastewaters from treated wastewater sumps or other collection points. The pumping systems consist of a pumping station containing the water intake, a pumping well, and an elevated storage tank for emergency use. The pumps require foot valves, or one-way valves, in order to retain their charge of water.

The water is pumped through a manifold into the secondary or alternative distribution system.

Operation and Maintenance

Depending on the use (i.e., intermittent use in the case of fire-fighting supplies or regular in the case of irrigation supplies) in the dual distribution system, regular testing of the system is recommended.

Where Treated water can be used

Recycled treated waste water from treatment facility can be used for various non-potable purposes including:

- Irrigation of agricultural land/garden/open area surrounding buildings and facilities
- Commercial uses such as vehicle washing facilities, laundry facilities, external space washing, and mixing water for pesticides, herbicides, and liquid fertilizers.
- Dust control and concrete production for construction projects.
- Toilet and urinal flushing in buildings.

How treated water is supplied to Users

The treated water/ reclaimed water from treatment facility is delivered to customers/ users through a parallel network of distribution mains separate from the community's potable water distribution system. The reclaimed water distribution system becomes a third water utility, in addition to wastewater and potable water. Reclaimed water systems are operated, maintained, and managed in a manner similar to the potable water system.

Treatment Requirements

One of the most critical objectives in any reuse program is to ensure that public health protection is not compromised through the use of recycled water. Protection of public health is achieved by:

- Reducing or eliminating concentrations of pathogenic bacteria, parasites, and enteric viruses in the recycled water,
- Controlling chemical constituents in recycled water, and/ or
- Limiting public exposure (contact, inhalation, ingestion) to recycled water.

Determining the necessary treatment for the intended reuse application requires an understanding of the:

1. Constituents of concern in wastewater
2. Levels of treatment and processes applicable for reducing these constituents to levels that achieve the desired recycled water quality.

Levels of wastewater treatment are generally classified as preliminary, primary, secondary, and advanced. Advanced wastewater treatment, sometimes referred to as tertiary treatment, and is generally defined as anything beyond secondary treatment.

A number of technologies for wastewater treatment have been applied worldwide for different scale applications. Selection of the treatment system depends on many factors such as the quality of water required which in turn depends on the application type, cost constraints, operation and maintenance expertise and costs, energy requirement, etc.

Guideline 4.2.2

- **It is recommended to ensure Operation and Maintenance (O & M) of Decentralised/Centralised Wastewater Systems and Safe disposal of generated sludge in all settlements**

Possible ways to achieve the above are:

- a) All decentralized waste water treatment systems and centralised wastewater treatment systems installed in settlements should have at least one trained personnel on-site to perform the basic operations of the installed treatment system. This hold especially relevant for any large campus, townships, institute, etc.
- b) An annual maintenance contract (AMC) should be signed, preferably with the same agency which installed the treatment system to undertake the following
 - i. Ensure quality of treated wastewater meets national discharge standards (if available) for reuse and disposal though regular checks
 - ii. Maintain the system to ensure smooth operation
 - iii. Display monthly treated wastewater quality reports in the establishment office and on all common notice boards
- c) All wastewater treatments systems must dispose of the residuals or sludge in a sustainable manner. Possible ways of disposing the sludge could be:
 - i. On site sludge processing by using Effective Micro organisms that eat the sludge or drying and converting it into organic manure

- ii. Entering into a contract with a sludge disposal company that will process the sludge or arrangements with the Municipality/ local authority for safe disposal

Why it is required?

Effective O & M would lead to:

- Consistency in the performance of the treatment system
- Achieve 100% treatment efficiency
- Economizing the running cost of the system
- Enhance the shelf life of the installed treatment system
- Increase the reuse and recycling potential of the treated discharge
- Improve and maintain the desired quality of environment.

Guidance Notes

O & M compliance requirement:

For an effective O & M, following requirement needs to be taken care of:

1. Description of proposed wastewater system
 - Flow diagram indicating all unit operations and components
 - Main line, re-circulated effluent, sludge flows and design average/ peak values
 - Expected influent/ effluent concentrations and design efficiencies
2. Personnel Responsibilities
 - Outline of responsibilities of STP service employee
 - Routine monthly work schedules
 - Training on operational procedures to service employee
3. Operation of Facility

- Specific operational information and control techniques available for each unit operation
- Common operating problems from past experience and remedies
- Provision for sludge management viz., thickening, dewatering and reuse options

4. Maintenance

- Measures for routine maintenance to be performed daily, monthly and annual basis
- Provision for storeroom/ tool room with a list of all major tools required for, emergency equipment inventory, spare parts inventory, schedules and references of suppliers, etc

5. Sampling and Laboratory Testing

- Explanation of representative sampling of flows and the difference between grab and composite samples
- Exact location of each sampling point
- Description of how samples are to be collected in general
- List of tests to be performed and their nature and purpose, with appropriate references to approved methods for conducting tests

6. Records and Reporting

- Requirements for operator's worksheets and daily operating logs, including: operational parameters for each unit operation; power consumption, etc
- Annual & monthly report requirements including: operating data with monthly averages of daily flows, quality parameters viz., BOD, SS levels etc.
- Requirements for availability of records including O & M Manual, equipment suppliers' manuals, construction photographs
- Details of operating cost breakdown and a record system for monitoring plant costs

7. Treatment Works Safety

- Description of safety hazards involved with the operation of each unit operation in the process
- Description and requirements for an ongoing preventive safety program including education in safety procedures and training in first aid/ emergency procedures
- Listing of safety rules and process equipment and laboratory

8. Utilities

- List of utilities servicing treatment works with contact personnel within utility company
- Reliability of electrical service and effect on continuous operability of process
- Breakpoints in utility/ treatment plant responsibilities

Guideline 4.2.3: Water reuse and recycling (including rainwater harvesting) for all settlements

- It is proposed that all settlements should aspire for at least 10%⁵ of the entire annual water demand is met through adequately stored and maintained rainwater for potable/ non potable applications and/ or ensure at least entire potable water demand during scarcity days (wherever the problem exists) is met by rooftop harvested rainwater.
- Ensure some of the irrigation water demand (in adjoining agricultural areas of settlements) is met through recycled water from settlements. However, adequate measures to maintain the quality for agricultural applications should be followed.
- Wherever mechanised or biological treatment systems treating to the level of secondary stages is installed at settlement level, ensure that the treated water is either put to use for agricultural application as stated above or used for toilet flushing or any other non-potable application.
- Every settlement-new and old can plan installation of preferably biological treatment system in phases either at a centralised location or decentralised catering to community scale.

⁵ This target percentage can be fixed by each municipality or Dzongkhag based on their need assessment and future projections

- The Bhutan Building Rules 2002 and the Draft Development and Construction Rules for non-planned settlements of Bhutan 2012 may further add provisions for 'Improved Septic tanks' in place of the conventional septic tanks and soak pits.

Bhutan, currently, does not have much installed capacity of treating the wastewater. In 2008, an eco-friendly sewage treatment plant (ecoline) was commissioned in Trashigang town for a capacity of 850 houses and is suitable for remote areas.⁶ Earlier, people had to clean their septic tanks and discard all the waste in the nearby stream (adding biological load on the water).

Thimphu, the capital city, has a lagoon system for treating its wastewater but is now not able to meet the current treatment demands. In a recent ADB initiative, installation of wastewater treatment system based on mechanised treatment for a capacity of 14 MLD is under process⁷.

There is a consensus on the need for having appropriate wastewater treatment systems at all settlements and these guidelines shall help in furthering and implementing this.

Rainwater harvesting potential for storage applications

In Bhutan, precipitation varies significantly with the elevation. The average rainfall varies from region to region⁸.

- Himalayan regions -Less than 500mm per year.
- Inner central valleys- 500mm to 1000mm per year.
- Southern foothills -2000mm to 3500mm per year.
- Southern border area- 3000mm to 5000mm per year

⁶ Sanitationupdates.wordpress.com

⁷ <http://www2.adb.org/documents/rtps/bhu>

⁸ <http://www.lonelyplanet.com/Bhutan/weather>

Assuming an area of 100 sq. m with run-off coefficient of 0.8, all these regions have enough potential to conserve rainwater from the roof top of buildings and either use it for dry days or to meet at least the potable water requirements for the entire year.

Region	Potential of harvesting water from rooftop (kL)
Himalayan regions	40
Inner central valleys	80
Southern foothills	160-280
Southern border area	240-400

This is especially relevant for places like Mongar, where increasingly incidences of shortage of water during summers are felt. Places where there is likely contamination of surface water courses during some seasons and which get their supplies from such water may also depend more on rooftop stored rainwater for potable applications. This can either be taken up at each household level or at neighbourhood scale. Rainwater harvesting may also help control erosion and flooding during periods of excessive rainfall.

Implementation issues are not very big, Apart from capacity building and generating general awareness among the people, apprehensions on increased investment cost needs to be taken care of. Financial investment is minimal with building owners required to purchase gutter for channeling of water to tank, a tank, and an electric motor to pump the water from lower tank to existing tank. For the local authorities, this means less energy required to treat water thereby benefitting the environment.

Integrated rainwater harvesting may also help the agricultural production which is currently dependent on the rains. Some of the strategies suggested are:

- Micro-catchment runoff farming water harvesting systems
- Macro-catchment runoff farming water harvesting systems
- Floodwater harvesting runoff farming (also called large catchment water harvesting or spate irrigation)

Rainwater harvesting systems for agricultural applications are however, not within the purview of current study (which is focused on settlements)

Implementation mechanism:

The government can influence the demand by affecting the supply cost by either taxation or subsidy and increasing the tariff on water to discourage use.

Improvise Septic tanks

In this improvised version of septic tanks, baffled reactors are created with additional pipes for flow of sewage from one tank to another. This enhances the treatment capacity substantially, which is otherwise not possible in the conventional septic tanks.



Figure 13 : Improvised Septic Tank

(Source: CSE, Do-it-yourself:Recycle and Reuse Wastewater)

Guideline 4.2: Sustainable Storm water management

Sustainable storm water management entails the following guidelines:

- a) All settlements should adhere to natural site contours and reduce hard paving
- b) All settlements should provide for an efficient storm water management system
- c) If buildings have basements, there should be adequate provisions for storm water management in basements

There should be minimal disturbance, grading of the land or stripping of vegetation on slopes of 30% or steeper. If at all it is essential to disturb such areas for utility construction or roads, it should be shown via analysis of alternatives that such improvements are necessary and affect the sloped area to minimum extent possible. Construction should not be allowed in any catchment area/ natural drainage areas such as gorges, water bodies, streams, etc.

Roads and driveways should follow the natural topography to the greatest extent possible in order to minimise the cutting and grading of critical slope areas. There are separate guidelines and environmental codes on this prevalent in the country. However, part compliance of some of measures such as soil erosion prevention, slope stabilisation through various measures, improper construction waste management is observed. This leads to impacting micro water shed areas in the long run and could have devastating impacts.



Measures should be taken to reduce hard paving on site to reduce stormwater runoff attenuation and infiltration and reduce Urban Heat Island Effect⁹.

Ensure that the storm water management system is based on the principles of Sustainable Urban Drainage Systems (SUDS) for all settlements and campuses/ buildings; Ensure that the post-development peak run-off rate and quantity from 5-year 24-hour design storm does not exceed the pre-development peak run off rate and quantity; At least 50 % of the quantity should be treated by any of the SUDS techniques. The proposed system should be capable of also treating a minimum of 90% of storm water and achieve the following standards for quality control:

⁹ UHI is defined as the rise in temperature of any man-made area, resulting in a well-defined, distinct "warm island" among the "cool sea" represented by the lower temperature of the area's nearby natural landscape. Though heat islands may form on any rural or urban area, and at any spatial scale, cities are favoured, since their surfaces are prone to release large quantities of heat. Nonetheless, the UHI negatively impacts not only residents of urban-related environs, but also humans and their associated ecosystems located far away from cities. In fact, UHIs have been indirectly related to climate change due to their contribution to the greenhouse effect, and therefore, to global warming. (Source: <http://www.urbanheatislands.com/>)

- Maximum removal of Total Suspended solids
- Maximum removal of litter
- Maximum removal of hydrocarbons

Provide for adequate measures for storm water management in basements.

Why it is required?

The location of the site and its contours in the context of the local catchment area needs to be understood prior to commissioning of any construction project. The design of the structure needs to be in tandem with the natural site level differences so that there are no major obstructions in the drainage patterns, post-development. This integrated approach to the existing site characteristics shall reap benefits in several ways such as preventing soil erosion, maintenance of watersheds and natural water bodies, etc.

Several places in Bhutan have floods and flash floods (especially along the southern foothills) due to various reasons like intense rains on small and steep catchments, grazing and harvesting of forest products for domestic use, lack of infrastructure specific for storm water discharge, clogging of drains and small water bodies due to pollutant loading specially during and after storm events, blockage of natural drains from improper waste management, lack of systems to recharge ground water with runoff or to harvest rainwater, and unplanned urban development with relation to the drainage patterns.

Protection of rivers and ground waters from these effects requires changes to the approach to drainage and consideration of treatment facilities prior to discharge. A range of techniques as a part of Sustainable Drainage Systems are available to achieve this. They are a flexible series of options, which allow a designer to select those that best suit the circumstances of a particular site. It represents an integrated system of techniques aimed at storm water management and is the anti-thesis of the conventional drainage techniques followed for flushing storm water out of the site. SUDS can be understood simply as a formalised revival of these practices that aim at localised at-the-source management of storm water. Moreover, Structural storm water management solutions are capital intensive and require more stringent maintenance. Non-structural storm water management solutions (sustainable urban drainage systems) are more sustainable than conventional drainage methods because they:

- Contain and manage runoff flow rates at the site-level itself, reducing the impact of settlements on flooding
- Protect or enhance water quality by reducing pollutant concentration in storm water
- Are sympathetic to the environmental setting and the needs of the local community
- Provide a habitat for wildlife in watercourses for bio-diversity enhancement
- Encourage natural groundwater recharge(whenever appropriate)

Guidance notes

Guidance notes on reduction of Hard paving

Urban areas are characterized by their high-activity based buildings which require various subsidiary on-site requirements such as parking, walkways and similar other circulation arrangements. There is a pertinent need to categorize and demarcate these areas from other open areas which resulted in the paving of the same.

Increased Imperviousness:

Hard paving has led to increased imperviousness on site, which has resulted in increased storm water run-off during rains causing flooding and its associated unhygienic environs. They also have drastically reduced the infiltration potential of the ground, thus adversely affecting the natural recharging process of the ground water table. This presents a two-pronged effect where flooding is a water surplus issue and reduced percolation is a water shortage issue.

Impervious surfaces also collect massive organic and inorganic pollutants in various forms which get washed away along with storm water runoff. This runoff gets stagnated in habited areas acting as propagation media for numerous pathogens spreading water-borne/ related diseases apart from heavy metals. Pollutant-laden runoff has been responsible for most of the groundwater contamination and almost all surface water bodies are polluted. Lack of filtration channels—albeit natural or manmade, has resulted in this situation.

Higher ambient temperatures:

City temperatures are higher due to lack of trees, shrubs and other plants to shade the buildings, pavements etc. by intercepting solar radiation and cool the air through evaporation. Buildings and pavements made of dark materials absorb solar radiation excessively causing the temperature of the surface and air in contact rise sharply.

Poor air quality:

UHI also reduces the air quality by increasing percentage of smog in air. Smog is created by photochemical reactions of pollutants in the air. These reactions are more likely to occur and intensify at higher temperatures.

Where paving is required, the use of permeable, pervious or porous paving materials will have the following direct and indirect advantages-

- Increased infiltration of storm water runoff into the ground water table or aquifer. Depending on design, paving material, soil type, and rainfall, permeable paving can infiltrate as much as 70% to 80% of annual rainfall.
- Grass pavers can improve site appearance by providing vegetation
- Provides onsite storm water run-off attenuation allowing infiltration thus reducing the risk of water-logging and flooding in low-lying areas

- Act as a primary water quality treatment medium that captures the suspended solids from trickling through, thus preventing the ground water contamination.
- It reduces the need for storm water conveyances and treatment structures, resulting in cost savings elsewhere.
- Reduces the amount of land needed for onsite storm water management as it may satisfy requirements for green space, allowing more paving on a site.

Guidance notes on SUDS

- Structural stormwater management solutions include engineered structures such as pipes, concrete channels, etc.
- Non-structural stormwater management solutions include sustainable urban drainage systems (SUDS) such as ponds, vegetated swales, wetlands, etc. Water infiltrated through such systems is considered to be 100% treated, achieving all the requisite quality control standards.

SUDS are primarily aimed at optimal storm water management by-

- Dealing with runoff close to where the rain falls
- Managing potential pollution at its source for present and future site conditions
- Protecting water resources from point pollution (such as accidental spills) and diffused sources.

SUDS can be designed to fit into all developments, from hard surfaced areas to soft landscaped features, as there are many design options available. They can be designed to improve amenity and biodiversity in developed areas. For instance, ponds can be designed as a local feature in large sites for recreational purposes and to provide valuable local wildlife habitat nodes and corridors. This variety of options allows designers to consider local land use and the needs of local people when undertaking the drainage design, as well as considering the traditional engineering components of the design, such as peak flow and capacity in the system. The SUDS management train is a useful concept in the development of a drainage system and illustrates the methodology of operation of SUDS as given in the adjoining Figure 14. Just as in a natural catchment, a combination of drainage techniques can be used in series to change the flow and the quality of the runoff in stages.

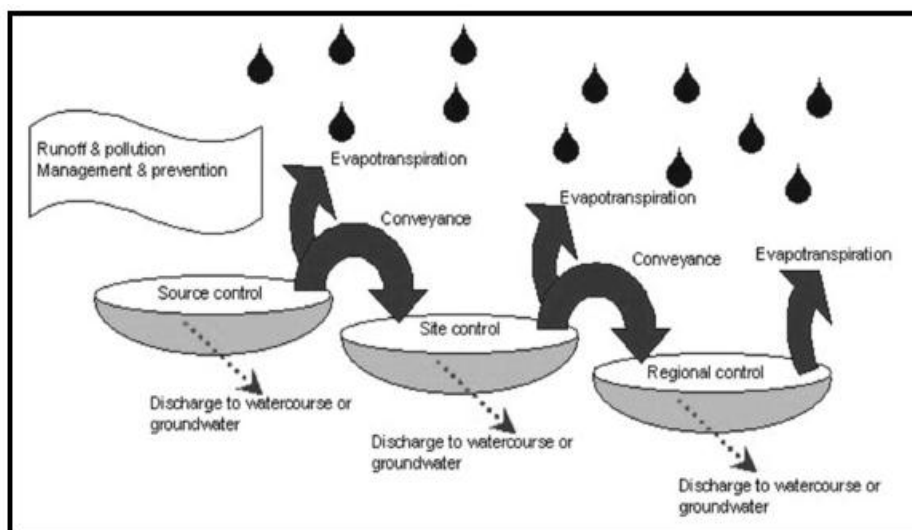


Figure 14: SUDS Management train-adapted from www.ciria.org

This concept is fundamental to designing a successful SUDS scheme – it uses drainage techniques in series to incrementally reduce pollution, flow rates and volumes. The hierarchy of techniques that should be considered in developing the management train are as follows-

Prevention– The use of good site design and site housekeeping measures to prevent runoff and pollution (eg: sweeping to remove surface dust and detritus from car parks) and rainwater reuse/ harvesting. Prevention policies should generally be included within the site management plan

Source control- Control of runoff at or very near its source (eg. Soak ways, other infiltration methods, green roofs, pervious pavements)

Site control- Management of water in a local area or site (eg. Routing water from building roofs and car parks to a large soak way, infiltration or detention basin)

Regional control– Management of runoff from a site or several sites, typically in a balancing pond or wetland

‘Best Management Practices’ or BMPs, which form a part of this management strategy are the application tools of SUDS and categorised under the following heads based on their utilitarian efficiency:

- Source Control & prevention techniques
 - Permeable pavement surfaces
 - Green Roofs
 - Rain water collection

- Infiltration devices
 - Infiltration trenches and basins
- Permeable conveyance systems
 - Filter strips and drains
 - Swales
- Passive treatment systems
 - Constructed wetland e.g. reedbeds
 - Detention and retention ponds

Pervious Pavements

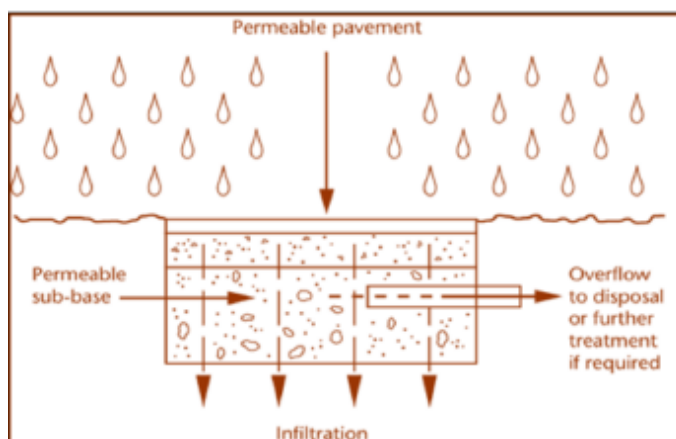


Figure 15 : Pervious pavements

Permeable pavement is an alternative to conventional paving in which water permeates through the paved structure rather than draining off it. Both the surface and the sub-grade need to be designed with this function in mind. Where the conditions are suitable the water may be allowed to infiltrate directly into the subsoil. Alternatively, it can be held in a reservoir structure under the paving for subsequent reuse, infiltration or delayed discharge, as shown in adjacent figure (Figure adapted from www.ciria.org). The permeable paving can be materials such as gravel, grasscrete, concrete blocks designed for the purpose or porous asphalt.

Overflows can be constructed on all these systems where a surface must be kept free of water in all conditions or where the base needs to be sealed to protect the aquifer.

Green Roofs

The system offers significant benefits in terms of reduction in the amount of water running off the roof, the rate of runoff and quality improvements. Many conventional flat roof systems used in industrial buildings could be converted to green roofs without exceeding design loadings and with the additional benefit of improving insulation and extending roof

life. Green roofs built with the most appropriate base and vegetation has the potential to absorb 15 – 90% of roof run-off. Figure 16 shows a green roof section with its typical components.

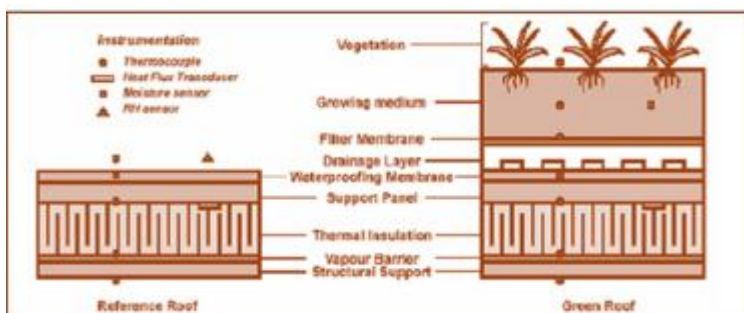


Figure 16: Green roof (Source: Karen Liu, PhD, from Proceedings of the Green Rooftops for Sustainable Communities Conference, Chicago, 2003, p.279)

Infiltration Trenches

An infiltration trench is a shallow, excavated trench that has been backfilled with stone to create an underground reservoir. Stormwater runoff flowing into the trench gradually infiltrates into subsoil. An overflow may be required for extreme rainfalls that exceed the capacity of the reservoir. The working mechanism of an Infiltration trench is illustrated in the adjacent Figure 17. The performance of the trench depends largely on the permeability of the soil and the depth to the water table. In common with other source control techniques, infiltration trenches usually serve small catchment areas, perhaps up to 2-3 hectares. The closer they are to the source of the run-off the more effective they will be. The operational life of the trench may be enhanced by providing pre-treatment for the inflow, such as a filter strip, gully or sump pit, to remove excessive solids. Regular maintenance will be required for most pre-treatment designs. Pollutant removal mechanisms include adsorption, filtering and microbial decomposition in the fill media and the soil below the trench and trapping of particulate matter within pre-treatment areas. Properly constructed and maintained, infiltration trenches can significantly reduce levels of solids, coliforms, trace metals and organic matter. Levels of phosphate and nitrate can also be reduced.

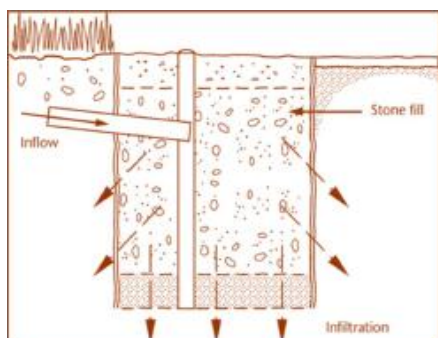


Figure 17: Infiltration trench

Infiltration Basins

Infiltration basins are shallow, surface impoundments where storm water runoff is stored until it gradually infiltrates through the soil of the basin floor as given in the adjacent schematic layout. An overflow may be required for extreme rainfall events which exceed the capacity of the reservoir. The performance of the basin depends largely on the permeability of the soil and the depth to the water table. Infiltration basins can serve larger catchment areas than infiltration trenches because a larger volume of water can be stored on the surface. They can typically serve catchments of up to 10 hectares. All other features are similar to the Infiltration Trenches.

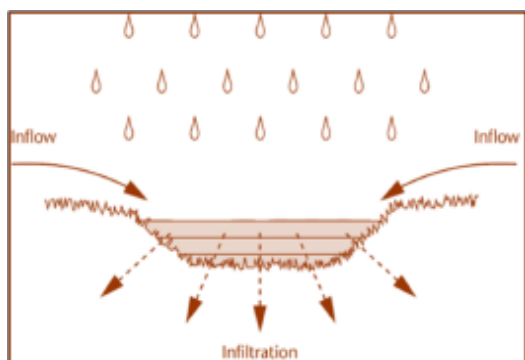


Figure 18: Infiltration basin

These move runoff water slowly towards a receiving watercourse, allowing storage, filtering and some loss of runoff water through evaporation and infiltration before the discharge point. There are two main types: underground systems, such as filter drains (or French drains) and surface water swales.

Filter Drains

The underground systems are known as filter (or French) drains. They comprise a trench, filled with gravel wrapped in a geo-textile membrane into which runoff water is led, either directly from the drained surface or via a pipe system. The gravel in the filter drain provides some filtering of the runoff, trapping sediment, organic matter and oil residues that can be broken down by bacterial action through time. Runoff velocity is slowed, and storage of runoff is also provided. Infiltration of stored water through the membrane can also occur and some filter drains need not lead to a watercourse at all. Filter drain systems have been widely used by the highway authorities for roads drainage

Swales

Swales are grassed depressions which lead surface water overland from the drained surface to a storage or discharge system, typical using the green space of roadside margins. When compared to a conventional ditch, a swale is shallow and relatively wide, providing temporary storage for storm water and reducing peak flows. They are appropriate close to

source and can form a network within a development scheme, linking storage ponds and wetlands. A swale is dry during dry weather but during a rainfall event water flows over the edge and slowly moves through the grassed area. The flow of surface water is retarded and filtered by the grass. Sediment is deposited and oily residues and organic matter retained and broken down in the top layer of soil and vegetation. Swales can be lined below the soil zone where necessary, to protect the underlying aquifer. During a rainfall event a proportion of the runoff can be lost from the swale by infiltration, and by evaporation and transpiration. If necessary, overflows can be placed at high level to provide conveyance in times of exceptionally heavy rainfall. Swales should be designed to be dry between storm events to enhance their pollutant removal capability.

Passive Treatment Systems

Passive treatment systems use natural processes to remove and break down pollutants from surface water runoff. Small scale systems such as filter strips, can be designed into landscaped area, and are sited upstream of other SUDS. Larger, end of pipe systems usually involve storage of water in constructed ponds where natural purification processes can be encouraged. Constructed wetlands and ponds also provide the opportunity to improve wildlife habitat in urban areas. Additionally, ponds can be made into amenity features for the local community.

Filter Strips

Filter strips are vegetated sections of land designed to accept runoff as overland sheet flow. In order to be effective they should be 5 – 15 metres wide and they may adopt any natural vegetated form, from grassy meadow to small wood. The wider the strip and the more dense the vegetative cover the better the pollutant removal.

Detention Basins

Detention basins are designed to hold back storm runoff for a few hours to allow the settlement of solids. Bypasses may be included to ensure the first flush is detained. Detention basins drain via an orifice or similar hydraulic structure into a watercourse or surface water drainage system. Detention basins are dry outside of storm periods. They are designed to retain flood events, reducing peak flows and limiting the risk of flooding. Solids removal is the chief feature of detention basins, and high removal rates are possible. Nutrient and trace metals removal is more modest. Extended detention basins incorporate a small permanent pond or wetland which can enhance the appearance of the basin.

Pollutant removal can be maximised by allowing up to 24 hours detention and seeking to treat a modest volume of runoff. It may be better to treat the first flush of runoff from the catchment and by-pass the rest, rather than to scour out settled silt by passing the full storm flow through the basin. Performance is further enhanced with retention ponds and wetland pond systems.

Retention Ponds

Retention Ponds retain a certain volume of water at all times. This can avoid possibly unsightly exposure of banks of collected sediment and enhance performance in removing nutrients, trace metals, coli forms and organic matter. Allowance for a considerable variation in water level during storms should be incorporated in the design, so that a significant

storage volume can still be provided. The permanent water may be visually more attractive, although elevated nutrient concentrations may result in algal blooms. To be successful as an amenity, a retention pond should have a catchment of at least 5 hectares and/ or a reliable source of base flow.

Wetlands

These are a further enhancement of retention ponds, and incorporate shallow areas planted with marsh or wetland vegetation. These provide a much greater degree of filtering and removal of nutrients by algae and, to a lesser extent, by incorporation into plant material.

Inlet and outlet sumps, as with detention basins and retention ponds, will enhance performance and might be considered almost obligatory, since excessive sediment can quickly overwhelm the shallow area. Only specially constructed wetlands should be used to treat surface water. It is not normally an acceptable practice to lead surface water into an existing, natural, wetland area.

Table 11 : Summary of SUDS Components

Pervious pavings	Surfaces that allow inflow of rainwater into the underlying construction or soil
Green roofs	Vegetated roofs that reduce the volume and rate of runoff and remove pollution.
Filter drains	Linear drains consisting of trenches filled with a permeable material, often with a perforated pipe in the base of the trench to assist drainage, to store and conduct water; they may also permit infiltration.
Filter strips	Vegetated areas of gently sloping ground designed to drain water evenly off impermeable areas and to filter out silt and other particulates.
Swales	Shallow vegetated channels that conduct and retain water and may also permit infiltration; the vegetation filters particulate matter
Detention Basins and Retention ponds	Areas that may be utilised for surface runoff storage as well as to provide water quality Treatment
Infiltration devices	Sub-surface structures to promote the infiltration of surface water to ground. They can be trenches, basins or soak-aways.
Pipes and accessories	A series of conduits and their accessories normally laid

Pervious pavings	Surfaces that allow inflow of rainwater into the underlying construction or soil
	underground that convey surface water to a suitable location or treatment and/or disposal. (Although sustainable, these techniques should be considered where other SUDS techniques are not practicable).
Constructed wetlands	Constructed Wetlands are ponds with shallow areas and wetland vegetation to improve pollutant removal and enhance wild life habitat

Source: Modified from the 'Interim Code of practice for SUDS'- National SUDS Working Group

MAINTENANCE

All drainage systems require management and maintenance. Maintenance costs are reduced as SUDS schemes can be managed as part of normal landscape care and avoids the need for expensive specialist contractors.

Conventional site drainage which uses gullies, pipes, inspection chambers, and oil interceptors, requires regular specialist maintenance which is often neglected until pollution occurs.

Source Control elements require maintenance which can be accommodated by normal landscape management practice. The inherent design tolerances of BMP techniques prevent catastrophic failure as well as background pollution of the environment

Guidance notes on Storm water management in Basements

Storm water management in Basements is a very vital part of the entire gamut of sustainable runoff control. Often this aspect of drainage control is viewed more from the perspective of giving an immediate solution to a risky disturbance, than trying to integrate the same into the entire site's storm water drainage management regime. Basements provision is there in the Bhutan Building Rules 2002. In case the basements are used for vehicular parking, the storm water running through these spaces may get highly polluted with vehicular spills such as oils, fuel, sand and silt, etc. Basement storm water management hence becomes an area of concern that requires additional focus on pollutant-load reduction also through provision of adequate filters.

SECTION 5: SOLID WASTE MANAGEMENT

Bhutan has a very comprehensive regulation on waste management. The Waste Prevention and Management Regulation, 2012, which came into effect on 18 April 2012 in Bhutan is a well laid-out regulation for the waste minimization and management. It establishes various agencies and monitoring authorities for the effective implementation of this regulation, and is applied to all point sources and/ or point of origin of different types of waste and their management.

The prime objective of these regulations is to close the waste cycle loop and to follow a more systematic, integrated approach to waste management. Solid Waste Management covers all activities pertaining to the control, transfer, transport, processing and disposal of solid waste in accordance with best principles and practices of public health, economics, engineering, conservation and aesthetics.

The best method to deal with waste is centered on a broadly accepted “Hierarchy of waste management” which gives a priority listing of the technical and sociological options of waste management. The hierarchy gives general guidelines on relative desirability of the different management options.

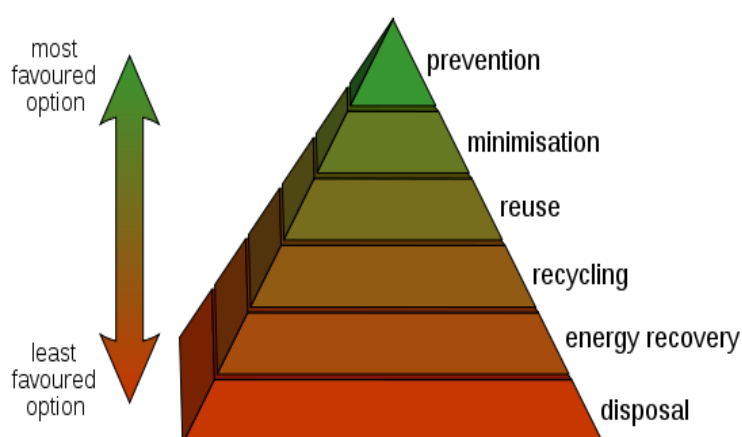


Figure 19 : Hierarchy of integrated solid waste management

The highest and most preferred rank of this integrated management hierarchy is waste prevention or waste minimization at source, which aims at reducing the amount of the waste produced. It is the most effective way to reduce the quantity of disposable waste, the cost associated with its handling and its adverse environmental impacts.

Reuse, recycling and energy recovery technologies then come as moderately suitable technologies. Land-filling is the last option of the hierarchy that involves controlled interment of the residual waste which has no further use on or in the earth's mantle.

National Environment Commission (NEC) is the apex monitoring body under this regulation which shall coordinate and monitor the overall performance of Implementing

Agencies designated to efficiently implement the provisions of this Regulation and, the Royal Bhutan Police shall assist the implementing agencies in achieving full compliance.

This regulation is a strong measure to deal with the existing bad scenario of waste disposal and management in Bhutan. It provides for restriction of sanitary landfill or open dump site in certain locations such as within a distance in or around human settlements, near water catchment areas, rivers, wetlands or ground water sources, landslide prone areas, notified area of endangered wildlife habitation and near monuments.

This regulation has laid down many provisions for handling and management of hazardous or infectious waste which are to be followed by implementing agency such as to have in place a system for safe storage, handling and disposal of hazardous wastes, providing personal protective equipments, labeling of containers having hazardous contents and maintaining detail records regarding incidents of injuries, accidents and non-compliance to the regulation.

For waste management services, the implementing agency in consultation with the Sanitary Committee may formulate collection mechanisms and propose chargeable fee amount that may vary for residential, commercial institutions and corporations. The fees, charges and fines collected are used for purposes such as outsourcing of waste collection services; public education and awareness programs; fund research, technical capacity development programs; cleaning campaigns, maintenance of existing waste management infrastructures; and incentives & awards for exemplary waste management initiatives.

The implementation agencies or responsible authorities for the general provisions are:

1. The National Environment Commission
2. The Royal Bhutan Police
3. Dzongdag monitoring authority within Dzongkhag jurisdiction
4. Dungpa, Gup, Mangmi, Divisional Forest Officer, Park Managers and institutional heads shall be the implementing agencies within respective territorial jurisdictions
5. Department of Roads in collaboration with the Road Safety and Transport Authority
6. Sanitary committee

WASTE MANAGEMENT CATEGORIES

Importantly, this regulation covers all kinds of waste and has separate provisions for their management. This regulation classifies wastes into four categories for the purpose of clearly demarcating the roles of implementing agencies under respective waste categories for the effective waste management. The provisions under these four waste management categories are as follows:

A. Medical Wastes Management

Under this section, the Ministry of Health and the Ministry of Agriculture and Forests shall monitor the Implementing agencies which include health clinics, hospitals, BHUS, Department of Livestock, Bhutan Narcotic Control Agency and Drug Regulatory Authority.

B. Municipal Waste Management

Under this section, the *Ministry of Works and Human Settlement* shall be responsible for monitoring the implementation within the jurisdiction of Thromde with the help of municipal offices of the Thromde and Dzongkhag as implementing agencies.

Some of the responsibilities to be undertaken by Thromde for managing municipal waste are:

- Proper waste management including segregation, collection, processing, transport and disposal to designated sites
- Provide separate containers for biodegradable and non-biodegradable wastes at every point source for the waste segregation
- Collect waste management service fees and other charges
- Safe handling, storage and disposal of hazardous or infectious waste
- Collection and treatment of leachate from a sanitary landfill before its release into the environment
- Conduction of advocacy programs and awareness programs.

The implementing agencies shall designate Thromde Inspectors for the effective implementation of the municipal waste management provisions under this regulation. Responsibilities are entrusted to waste traders and scrap dealers to ensure cleanliness while dealing with municipal wastes, provide protective equipment to their workers and ensure suspicious recyclable wastes are not purchased.

C. Industrial Waste Management

Under this section, the Ministry of Economic Affairs in cooperation with other related agencies shall monitor the implementing agencies.

Incentives like exemption from Bhutan sales tax, Income tax and custom duties for 20 years, exemption from license fee etc. may be provided to any licensed person engaged in the activities of waste collection, recycling, reuse or value addition to the waste.

Under this section a Waste Management Fund is established which deposits any revenue generated from the implementation of this regulation and is used for many activities related to waste analysis, minimization and management initiatives.

D. E-Waste Management

The provisions under this section shall be implemented by the e-waste management entity and the Thromdes, Dzongkhags, Gewog and Chiwog with overall directives and guidelines from the Department of Information Technology and Telecom monitoring the implementation by the e-waste management entity.

This section has laid down detailed provisions for every producer, importer, exporter, transporter, consumer or bulk consumer for the management and handling of e-waste.

An E-waste fund is created under this section by the Department of Information Technology and Telecom in consultation with the NEC to finance the implementation of e-waste management system and carry out related tasks.

There is an entire chapter under the Waste Prevention and Management Regulation, 2012 dealing with Waste management in government reserved forest including protected areas and Dzongkhag communities. The implementing agency for this purpose is the Divisional Forestry Officer or Park Manager and the monitoring authority is the Ministry for Agriculture and Forests.

The guidelines for solid waste collection and transportation within communities are also mentioned under this section. A Regional Waste Collection Centre may be coordinated by different Dzongkhags to promote economic viability of inorganic solid waste for the reuse or recycling purposes by interested agencies.

Fine and administrative action

This regulation imposes fines and administrative actions on individuals or organizations for various offences.

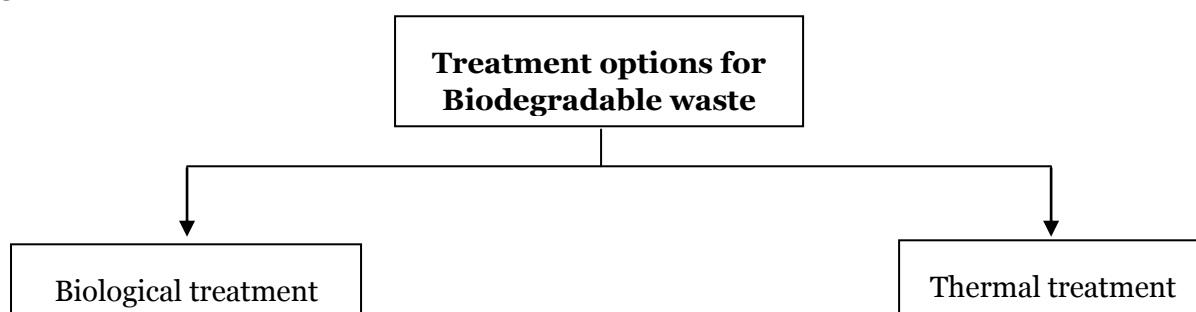
The Waste Prevention and Management Regulation, 2012 in Bhutan seems to be a well laid legislation covering all aspects related to waste management issues of the country but importantly implementation is yet to be seen. The regulation is holistic in terms of clear responsibilities, duties, penalty clauses, implementing agency roles, etc. and shall become a role model for other countries to follow if implementation also happens as envisaged.

Guideline 5.1: Organic /Biodegradable waste treatment

The management system for municipal solid waste is clearly laid out in the Waste Prevention and Management Regulation, 2012. To further help in implementation by the respective authorities and the Ministry of Works and Human Settlement,, following guidance notes provide for some solutions on treatment of biodegradable/ organic matter which can be taken up at centralised level or at community scale/ building level.

Technology for treatment of organic/ biodegradable waste

Technology selection is primarily guided by the kind and type of waste composition. The solid waste generated in and around settlements comprise of almost 50 per cent of biodegradable waste. Such waste can be biologically or thermally treated. Various kind of technology options available for the processing of biodegradable waste and the parameters which should be considered for selection of the treatment option are given in the adjoining figure.



Biological Processes

Biological treatment involves using micro-organisms to decompose the biodegradable components of waste. Two types of processes are used, namely:

- a) Aerobic processes: Windrow composting, aerated static pile composting and in-vessel composting; vermi-composting, composting with bioculture method etc.
- b) Anaerobic processes: Low-solids anaerobic digestion (wet process), high-solids anaerobic digestion (dry process) and combined processes.

In the aerobic process the utilizable product is compost. In the anaerobic process the utilizable product is methane gas (for energy recovery). Both processes have been used for waste processing in different countries – a majority of the biological treatment process adopted world-wide are aerobic composting; the use of anaerobic treatment has been more limited. In the neighbouring country India, aerobic composting plants have been used to process up to 500 tons per day of waste.

Vermicomposting

In this type of composting, the process of composting is accelerated by introducing deep burrowing earthworms or surface earthworms.(the usual red worms).

Vermicomposting by use of Surface earthworms:

- They eat the waste and vermi-compost is the excreta that they leave behind.
- This occurs after absorbing the nutrients for their own life cycle and leaves a higher fungal and actinomyte count, which is not beneficial to plant growth, due to reduced oxygen and helpful microbial count.
- Higher maintenance as they require dung (expensive)



Vermicomposting from deep burrowing earthworms

- Vermicompost is produced by breaking down of food leftovers by micro-organisms in the soil, encouraged through aeration by the deep burrows caused by deep burrowing earthworms.
- These earthworms are soil eating. They grind minerals into soil in their digestive systems, thereby creating new soil. can be used to create arable soil
- Nutrients are considered to be of high value because of the existence of a higher total count of helpful micro-organisms and a larger number of nitrifying bacteria and phosphate solubilisers in them, which help plant growth.
- Smaller quantities of deep-burrowing earthworm vermi-compost required in comparison to that of surface earthworms,
- production process less cumbersome
- Requires 1sqm for 1 kg waste or 7 potted plants per household

The availability of both type of earthworms needs to be checked for Bhutan .

Effective microorganism or Biosanitisers

Organic solutions such as Effective Micro-organisms is a liquid concentrate of specially cultured microorganisms and are very useful in enhancing the composting. Originally developed by Dr. Teuro Higa at the University of Ryukus, Japan, the solution is now available in India (neighbouring country). The solution has to be activated with molasses or rice water; activated solution is then sprayed on a batch of mixed garbage of 3-4 m. width & 2 m.ht. It takes 4 to 8 weeks for composting and the stink usually associated with composting is gone. It can also be used by single household too.

Biomethanisation converts organic waste into gas (Methane) and compost and is feasible for organic waste generation of atleast 50 kg or preferably 100 kg per day. As a result, this is useful for installation in large monasteries, institutions, townships or small settlements or community scale.

Some of the common bio-methanation based digesters available in India are as follows:

- TEAM digester (developed by The Energy and Resource Institute (TERI))
- ASTRA digester (Centre for Sustainable Technologies)
- ARTI digester (Appropriate Rural Technology Institute)
- SPRERI digester (Sardar Patel Renewable Energy Research Institute)
- BARC digester (Bhabha Atomic Research Institute)
- Mailhem Engineering PVT Ltd.

TEAM (TERI Enhanced Acidification and Methanation) is a high-rate digester for biomethanation of fibrous and semi-solid organic wastes.

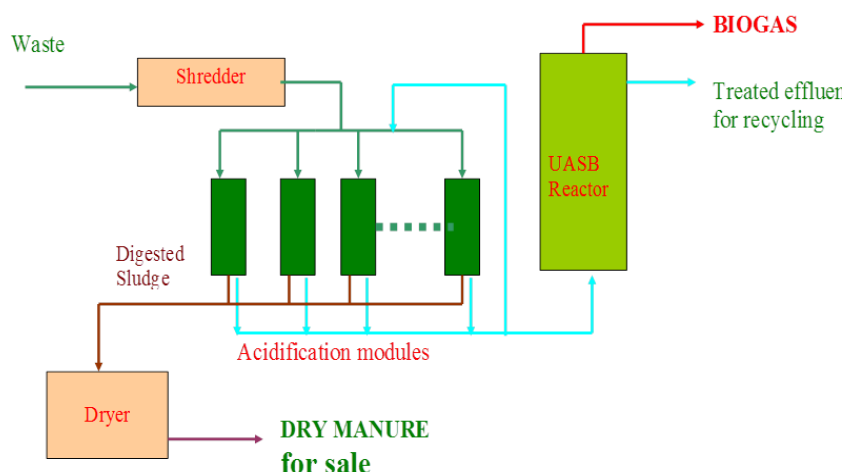


Figure 20 : Schematic of TEAM digester

Some of the key advantages of using TEAM digester are:

- Elimination of Scum formation - a feature in small size plants.
- Proven performance of pilot plant (in India) since Jan. 1999.
- Low capital cost compared to imported design
- Energy and enriched manure
- Suitability for small and decentralized application
- Very low water requirement due to recycling
- Low maintenance cost
- Ease in material handling
- Process suitable for adaptation by small entrepreneurs

Thermal Processes

Thermal treatment involves conversion of waste into gaseous, liquid and solid conversion products with concurrent or subsequent release of heat energy. Three types of systems can be adopted, namely:

- a) Combustion systems (Incinerators): Thermal processing with excess amounts of air.
- b) Pyrolysis systems: Thermal processing in complete absence of oxygen (low temperature).
- c) Gasification systems: Thermal processing with less amount of air (high temperature).

Combustion system is the most widely adopted thermal treatment process world-wide for MSW. Though pyrolysis is a widely used industrial process, the pyrolysis of municipal solid waste has not been very successful. Similarly, successful results with mass fired gasifiers have not been achieved.

Three types of combustion systems have been extensively used for energy recovery in different countries namely:

- a) Mass-fired combustion systems (MASS),
- b) Refuse Derived Fuel (RDF),
- c) Fired combustion systems and Fluidized Bed (FB) combustion systems

To be viable for energy recovery through thermal processing, the organic waste must possess a relatively high calorific value. In the MSW generated in developed countries, presence of significant quantity of paper and plastics yields a high calorific value of the MSW (typically above 2000 kcal/ kg) which makes it suitable for thermal processing. In case, the calorific value of organic waste is lesser thermal processing may not be feasible. It is therefore, important to study the calorific value of municipal waste streams for various

locations (there could be regional differences in the waste stream and calorific value) as well to arrive at a feasible centralised treatment option for organic waste.

Parameters to be considered for selection of the treatment option for biodegradable waste

Some of the parameters which should be considered for selecting the treatment type are listed as under:

- Capital cost
- Operation & Maintenance cost
- Composition of the waste, it's calorific value
- Land requirements
- Sensitivity of the treatment technology to external parameters like temperature, humidity, oxygen level, etc
- By-products
- Social acceptability
- Pay-back period
- Finances
- Viability of the scale of operation

Guideline 5.2: Construction & Demolition (C & D) waste management

The Waste management and prevention regulation 2012 has some provision for construction waste as part of the municipal waste. This section further gives guidance on enhancement of the management process.

Construction and demolition waste is generated whenever any construction/ demolition activity takes place, such as, building roads, bridges; fly over, subway, remodelling etc. It consists mostly of inert and non-biodegradable material such as debris, concrete, steel, plaster, metal, wood, plastics, packaging and paper products, fluorescent tubes, light fixtures, tiles, paints, etc.

These wastes are heavy, having high density, often bulky and occupy considerable storage space either on the road or communal waste bin/ container. It is not uncommon to see huge piles of such waste, which is heavy as well, stacked on roads especially in large projects, resulting in traffic congestion and disruption. Waste from small generators like individual house construction or demolition, find its way into the nearby municipal bin/ vat/ waste storage depots, making the municipal waste heavy and degrading its quality for further treatment like composting or energy recovery. Often it finds its way into surface drains, choking them. It constitutes about 10-20 % of the municipal solid waste (the correct percentage may only be determined once waste stream characterisation is done at the country level).

Construction industry generates a lot of waste annually. Also, the road construction currently going on in the country has huge requirement for aggregates. Recycling of aggregate material from construction and demolition waste may reduce the demand-supply gap in roads sector.

Concrete and masonry waste can be recycled by sorting, crushing and sieving into recycled aggregate. This recycled aggregate can be used to make concrete for road construction and even building material. Work on recycling of aggregates has been done at Central Building Research Institute (CBRI), Roorkee, and Central Road Research Institute (CRRI), New Delhi, India, whose help may be taken for Bhutan specific research and use applications.

Characteristics of C & D waste

This category of waste is complex due to the different types of building materials being used but in general may comprise of the following materials:

Major components

- Cement concrete
- Bricks
- Cement plaster
- Steel (from RCC, door/ window frames, roofing support, railings of staircase etc.)
- Rubble
- Stone (marble, granite, sand stone)
- Timber/ wood (especially demolition of old buildings)

Minor components

- Conduits (iron, plastic)
- Pipes (GI, iron, plastic)
- Electrical fixtures (copper/ aluminium wiring, wooden baton, bakelite/ plastic switches, wire insulation)
- Panels (wooden, laminated)
- Others (glazed tiles, glass panes)

Steps for Integrated management of C & D waste.

A. STORAGE OF CONSTRUCTION AND DEMOLITION WASTE

These wastes are best stored at source, i.e., at the point of generation. If they are scattered around or thrown on the road, they not only cause obstruction to traffic but also add to the workload of the local body. For large developmental projects special provision should be made for storage and handling of waste material. All attempts should be made to stick to the following measures:

- a. All construction/ demolition waste should be stored within the site itself. A proper screen should be provided so that the waste does not get scattered and does not become an eyesore.
- b. Attempts should be made to keep the waste segregated into different heaps as far as possible so that their further gradation and reuse is facilitated.

- c. Material, which can be reused at the same site for the purpose of construction, levelling, making road/ pavement etc. should also be kept in separate heaps from those, which are to be sold for landfilled or processing.
- d. The client may arrange to provide appropriate number of skip containers/ trolleys on hire which may be parked at the site and removed with skip lifters or tractors as the case may be.

B. COLLECTION AND TRANSPORTATION

If the construction debris is stored in skips, then skip lifters fitted with hydraulic hoist system should be used for efficient and prompt removal. In case, trailers are used, then tractors may remove these. For handling very large volumes, front-end loaders in combination with sturdy tipper trucks may be used so that the time taken for loading and unloading is kept to the minimum.

For small generators of construction debris, e.g., petty repair/ maintenance job, there may be two options – (i) specific places for such dumping by the local body and (ii) removal on payment basis.

In case of small towns where skips and tipping trailers are not available, manual loading and unloading should be permitted.

In case of large generators C & D waste should be reused for construction activities or must be sold to registered C & D waste recyclers.

C. RECYCLING AND REUSE

The use of these materials basically depends on their separation and condition of the separated material. A majority of these materials are durable and therefore, have a high potential of reuse. It would, however, be desirable to have quality standards for the recycled materials.

Construction and demolition waste can be used in the following manner:

- a. Reuse (on site) of bricks, stone slabs, timber, conduits, piping railings etc. to the extent possible and depending upon their condition.
- b. Sale / auction of material which can not be used at the site due to design constraint or change in design.
- c. Plastics, broken glass, scrap metal etc. can be used by recycling industries.
- d. Rubble, brick bats, broken plaster/ concrete pieces etc. can be used for building activity, such as, levelling, under coat of lanes where the traffic does not constitute of heavy moving loads.
- e. Larger unusable pieces can be sent for filling up low-lying areas.
- f. Fine material, such as, sand, dust etc. can be used as cover material.

D. DISPOSAL

Being predominantly inert in nature, construction and demolition waste does not create chemical or biochemical pollution. Hence maximum effort should be made to reuse and recycle them as indicated above. The material can be used for filling/ levelling of low-lying areas. However, proper sampling of the material for its physical and chemical characteristics has to be done for evaluating its use under the given circumstances.

Stages of Waste Minimization

There are three key stages where waste minimisation and reuse initiatives should be introduced:

1. Contractual stage
2. Design stage
3. Site operation stage

At the contractual stage, the legal responsibility of project partners for minimizing waste during construction and properly managing waste is established by including clauses in the contract agreement.

At the design stage, firstly the client should clearly communicate the commitment to reducing environmental impact in design briefs and accordingly select a design team. The architect/ designer should consider the following:

- Materials specification: Avoidance of the following where possible
- Designs that require more material than necessary. E.g., over specification of the material quantities for beams or columns;
- Designs that restrict the use of reclaimed and recycled materials;
- Use of high embodied energy materials
- Sizing of members and components which involve a lot of wastage from cuts

Site operation stage is primarily done by the contractors and involves a structured methodology of three distinct phases.

Phase 1-Analysis and evaluation of waste management opportunities

This phase involves identifying the waste streams and causes of waste generation; evaluating the various options for waste segregation (on-site or off-site), options for recycling and reusing materials; deciding the final destination of waste material; designing spaces for storage of waste on-site, etc and drawing the final waste management plan.

Phase 2- Implementation

For successful implementation of the waste management plan, staff training and communication plays a very important role and is done at this phase.

Phase 3-monitoring

At this phase, the success of the waste management plan is determined by conducting survey at regular intervals.

List of hazardous wastes present in C & D waste:

1. Asbestos products-insulation, tiles, etc.
2. Fuels and heating oils and other volatile/ flammable liquids such as coolants, grease, etc.
3. Tar and Tar products (bitumen, felt, water proofing compounds, etc.)
4. Centering oil, formwork oil
5. Wood dust
6. Lead
7. Plastics, Acrylics, Silica, PVC
8. Chemical admixtures, sealants, adhesives solvents etc.
9. Paints, pigments, dyes and primers
10. Pesticides
11. Tarpaulin
12. Explosives and related products and equipment used in excavations
13. Product packaging (cement bags, cartons, containers, plastic covers, etc.)
14. Compressed gas/ cylinders
15. Mercury containing lamps and tubes-Fluorescent lamps intact and crushed, halogen lamps, arc lamps, UV lamps, high pressure sodium lamps, mercury vapour lamps, neon lamps, incandescent lamps.
16. Mercury containing devices-mercury switches, relays, regulators, thermostats, etc.
17. All types of batteries

18. Electronic ballast, PCBs, transformers, capacitors, switchgear, lead cable, oil filled/ gel filled cables.
19. Electronic waste-computer products, circuit boards, CRTs, electronic parts, solder dross, weld waste

SECTION 6: RISK MITIGATION / ADAPTATION AND CLIMATE CHANGE

Climate change is a potential threat that needs to be addressed at all levels. Two broad categories of response mechanism are identified by United Nations Framework Convention on Climate Change (UNFCCC) to deal with climate change, namely mitigation and adaptation.

‘Mitigation’ involves reducing the sources or enhancing the sinks of greenhouse gases. Adaptation refers to the ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damage, to take advantage of opportunities, or to cope with the consequences. Both responses are equally important and can help reduce the risks of climate change to natural and human systems.

Climate change not only increases the incidence of extreme events and disasters but also induces gradual changes such as temperature and precipitation changes, thus variability of climate is another important impact that makes resource management and infrastructure planning more challenging, and increases the urgency of the need to adapt city level operations to both current climate variability and future climate change. There is strong need therefore to plan for adaptation and mitigation actions at all levels by identifying prime sectors for intervention depending on projected impact of the climate for particular region.

As per the study, Bhutan National Adaptation Programme of Action, National Environment Commission, a study of temperature and rainfall and likely climate change impacts was done. Given the scarce resources, proper equipment, lack of capacity and trained manpower, projecting climate change in a meaningful and systematic manner was recognised as extremely difficult task. Reliable data exists for only about 10-12 years beyond which observations are not reliable enough to make any firm conclusions as climate predictions would need at least a few decades of observations. However, the analysis of available meteorological data for the past 13 years indicates an increasing trend in precipitation variability during the past 13 years across the country. Also, a clear indication on rising temperatures is observed.

As part of the NAPA program, top 9 prioritized projects have been shortlisted as shown below:

1. Disaster Management Strategy (Pilot Implementation of Food Security and Emergency Medicine)
2. Artificial Lowering of Thorthomi Glacier Lake
3. Weather Forecasting System to Serve Farmers and Agriculture
4. Landslide Management & Flood Prevention (Pilot Schemes in Critical Areas)
5. Flood Protection of Downstream Industrial and Agricultural Area
6. Rainwater Harvesting

7. GLOF Hazard Zoning (Pilot Scheme – Chamkar Chu Basin)

8. Installation of Early Warning System on Pho Chu Basin

9. Promote Community-based Forest Fire Management and Prevention

Of the above, projects where there is a definite role and involvement of settlements is Landslide management and flood prevention and Rainwater harvesting.

Important conclusions drawn from this study which is useful for settlements planning and building construction are:

- Increased vulnerability to landslides and floods
- Increase in temperature (more demand for space cooling in certain seasons especially in the southern region)
- Spread of vector-borne tropical disease (malaria, dengue) into more areas (higher elevations) with warming climate
- Loss of safe (drinking) water resources increasing water borne diseases.
- Interrupted supply of grid-based electricity from hydro-power plants

This section gives an introduction to climate change impacts and responses to these threats in the form of adaptation and mitigation. It underlines the need for settlements to plan for climate change impacts at neighborhood levels not only to prepare and withstand these impacts but also to enjoy the fruits of sustainable, climate and environment friendly development. Factoring climate change adaptation and mitigation into settlements would equip them to withstand shocks and threats that are yet unforeseen and sometimes unpredictable.

Adaptation at Neighbourhood level:

A lot of efforts on climate change adaptation are being carried out by several ministries under the guidance of National Environment Commission. However, adaptation planning at settlement level is yet to be undertaken. It is an established fact that adaptation and mitigation are operational on much smaller scales and their cumulative results would benefit at a larger scale. For example, energy efficient and climate responsive buildings that are less dependent on mechanical means for thermal comfort would help reduce considerable amount of energy use, thus indirectly leading to mitigation effort. Similarly, a colony with a storm water drainage network with a designed capacity to withstand flash floods during monsoon periods or any unforeseen heavy precipitation event as an outcome of climate change would make the area resilient to that particular climate impact or threat.

Also various elements of adaptation planning and mitigation activities are better designed at the level of the individual buildings, or colony, or a large campus or neighborhood. For example, while water conservation as an adaptation activity could be mandated by law in a settlement, but actual conservation would take place when the facility is built at the level of the building/ a community/ a colony or a campus.

Guideline 6.1: Planning for climate change adaptation in all settlements

There are no generic or tailor-made solutions available to help any development to be climate proof – one that encompasses adaptation and mitigation actions at the planning stage itself. However, different studies are available (Eckert et al, 2009¹⁰),(EU,2009¹¹) where such attempts have been made. This section draws from such studies and attempts categorization of adaptation and mitigation actions on the basis of the relevant climate impact. Impacts may vary from region to region and it is strongly recommended that settlements/ dzongkhags should allow for a settlement level risk assessment and vulnerability analysis to understand and plan settlement specific adaptation needs.

Table 12 : Climate change impacts and suggested adaptation measures at settlement level

Cause	Settlement Impact	Sectoral Response	Adaptation Measure
Change in precipitation – heavy ground level rise	Flooding and landslides Disrupted hydro-power based electricity	Land use planning	Conduct natural drainage pattern of the site analysis and place the built-up such that it allows for excess water to stream out rather than collect at various locations within settlement. Strong enforcement of soil erosion, sedimentation control measures At building level, provision for flood resilient construction (measures incorporated into the building fabric, fixtures and fittings to reduce the impact of floodwater on the property e.g., raising the plinth level, provision of damp proof membranes, locating electrical sockets above predicted flood level, protecting wiring by suitable insulation, etc.) Decentralised grid; alternative means of clean electricity such as solar, wind, biomass based
		Drainage systems	Managing flood pathways within site Providing for a well developed drainage system within site One way valves fitted in drains and sewage pipes to prevent backflow
		Water resource	Management of quantity of run-off water

¹⁰ 2009. Eckert Ronald and Schinkel Ulrikle.' Livable cities TP. Ho Chi Monh- Adaptation as response to impacts of climate change'. Proceedings REAL CORP 2009,Tagungsband,22-25 April 2009, Sitges.<http://www.corp.at>
¹¹ 2009. European Union. 'Adaptation to climate change-Policy instruments for adaptation to climate change in big European cities and metropolitan areas'.

		conservation-quality and quantity	Providing for collection of excess runoff on site and directing it to ground water recharge/sump-well for future use based on site suitability
			Rainwater harvesting mechanisms installed in buildings
			Drains cleaning mechanisms to ensure unhindered water flow in flood prone areas of the site.
		Health	Primary health care facilities available on site
			Mechanisms at place for prevention of water borne diseases
			At building level, ensure on-site clean source of water, provision of mosquito nets on the windows and openings
		Flood defence	Building outfalls and storage reservoirs, sluices
			Flood defence walls on the vulnerable side of the site – if adjoins river, canal , water body, hill or mountain foot etc (optional and very site specific measure)
Temperature rise	Heat wave	Increase proportion of green space	Linked network of well irrigated open spaces, green corridors
		Reduction of sealed surface	Green infrastructure like wetland restoration within site, trees, green roofs etc
		Increase water bodies	Construct artificial ponds, lakes, canals
		Solar control	Shading and orientation of buildings to reduce excessive heat gain
			Cool pavement materials to increase surface reflectivity
			Promotion of traditional housing typologies to capture natural climate friendly elements in design of site and buildings

Drought and water shortage	Ventilation	Natural ventilation
	Extensive rain water harvesting	Allow for compulsory rain water harvesting
	Water storage	Recharging and storing rain water to be used in summer season
	Fittings	Water Recycling systems installed in buildings Developers provide for efficient fittings /faucets
Others	Mitigation Measures	
	Site level facilities for pedestrian movements	
	Restriction on car use for demarcated areas; use of mass transport systems based on clean fuel technologies	
	Ensuring markets and utility areas within walking distance to discourage use of car and two-wheelers, provision of public transport outside/within campus	
	Promote design and orientation of buildings such that less need for mechanical means for thermal comfort. Solar passive design features could be used.	
	Provision of Green Areas/Plantation /green cover to improve air quality on site	

SECTION 7: BUILDING MATERIALS AND CONSTRUCTION TECHNOLOGIES

All buildings and infrastructure require materials for construction. These materials could either be high in embodied energy or low in embodied energy. There is an increasing trend worldwide including Bhutan to go for high embodied energy materials such as cement, steel, bricks, glass etc. The problem is further compounded in case of Bhutan which imports most of the building materials. There is therefore, an urgent need to look for alternative materials which are preferably available locally or can be manufactured locally. Apart from being high embodied material, many of the conventionally used materials become costly also due to being imported from the neighbouring countries. From environmental and poverty perspective, adoption of more and more locally available low embodied energy materials is highly desirable in the country.

Some of the alternative building materials/ technology which may be consciously promoted in the country are:

1. Compressed stabilized earth blocks
2. Hollow interlocking blocks
3. Bamboo

Apart from the above, Green Design Guidelines (currently under development by the Department of Engineering Services) shall further look at more strategies and solutions.

1. Compressed stabilised earth blocks:

The first and the most critical step in CSEB technology is identification of soil which is suitable for block production and will be available locally in the required quantity. CSEB gives the advantage of local manufacturing with less embodied energy involved (as compared with the regular kiln-burnt bricks and transported from far off places in India). It is also less polluting than the fired bricks (2.4 -7.8 times less¹²).

Soil, consisting of sand, clay and silt is the basic raw material for CEB. In general, soils containing 10 -15% clay and 60-75% sand are satisfactory for cement- stabilized CEB. It is preferable that the clay in the soil should be non-expansive, because it is extremely unstable in presence of water, although it can be stabilized in a complicated manner¹³.

If a stabilized CSEB is produced using a clayey soil – more than 20% clay and if the cement stabilization is less than 5%, the block is likely to develop cracks during alternate wetting and drying leading to surface cracks or spilling at corners after exposure to weather for 2-3 years. Such problems can be avoided by adding adequate quantity of sand to the soil mix to keep the percentage of clay below 15%.

¹² Auroville Earth Institute, 2005. Training manual on Earthquake resistant buildings with hollow interlocking blocks.

¹³<http://www.ruralhousingnetwork.in/technical/stabilized-compressed-earth-blocks>

Proper Testing of soil is to be done with respect to the composition of quality and particle size of sand & silt; which would aid in determining the quantity of cement/ stabilizing agent (fibres, lime, fly ash, straw, latex, resins, etc.) and soil improvement to achieve the desired strength.

CSEB is a very site specific material and if used properly can be a great boon as an alternative construction material.

Basic Data on CSEB (For 5% cement stabilized blocks)	
Dry compressive strength (after 28 days curing)	3 to 6 MPa
Wet compressive strength (after 28 days curing)	1.5 to 3 MPa
Dry bending strength(after 28 days curing)	0.5 to 1 MPa
Dry shear strength (after 28 days curing)	0.4 to 0.6 MPa
Water absorption by weight (after 28 days curing)	8 to 12% (test done after 3 days immersion)
Apparent bulk density (dry)	1700 to 2000 kg/ m ³

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Water absorption by weight (after 28 days curing)	8 to 12% (test done after 3 days immersion)
Apparent bulk density (dry)	1700 to 2000 kg/ m3

Source: Training manual on Earthquake resistant buildings with hollow interlocking blocks, Auroville Earth Institute

2. Hollow Interlocking blocks for earthquake resistance

This is a technology using reinforced hollow concrete block and has been used in various ways all over the world. Its principle is to reinforce the masonry by grouting a concrete into the hole of the block where stands a steel rod at the critical locations (like corners ends, near openings, etc.). Horizontal reinforcement is also cast in U-Shape blocks.



Hollow interlocking blocks are of two types

1. Hollow Interlocking Compressed Stabilised earth blocks (HI CSEB)
2. Hollow Concrete Block

The technology using Hollow interlocking Compressed stabilised earth Block (HI CSEB) is based on the same principle: to reinforce horizontally and vertically the masonry with Reinforced Cement Concrete (RCC) members. The advantage of hollow interlocking CSEB, compared to hollow concrete block, is that they offer keys, which interlock the other blocks thus these walls offer more resistance to shear and buildings would be even stronger. Such buildings can better resist earthquakes and without major damages.

Advantages:

- Biodegradable materials
- Energy efficiency and eco friendliness 5 – 15 times less energy consumed than fired brick and around 3 – 8 times less emission
- Cost effectiveness
- Minimum mortar required
- Keys that interlock with each other provides better integrity
- Hollow provisions for laying vertical and horizontal reinforcements to improve the lateral load resisting capacity

Limitations:

- Only for low rise structures: maximum 2 storey
- Strength very much dependent on the properties of soil
- Too much stabilization(cement) will make no economic sense
- Interlocking features do not provide air tightness. Minimum gap is formed due to which termite/ air current can pass.
- For frame structures, HI-CSEB can be used as filler materials but the structural member's sizes increases due to increase in the block weight.

HI-CSEB use in Bhutan

- Use of HI-CSEB blocks is reported in some areas such as Jemina in Bhutan.



Figure 21: A demonstration project using HI CSEB in Bhutan

Source: Presentation by Jigme Tenzin at the 6th Annual Engineering Conference

3. Bamboo

Bamboo has a great potential to solve the scarcity of sustainable building materials for high-end and affordable buildings in both urban as well as rural areas. The modern days building materials, which mainly constitute wood, concrete and steel are not consider sustainable materials because they are associated with high-embodied energy.

Some issues do exist such as using raw bamboos for the construction of houses have many advantages and disadvantages. Use of raw bamboos is generally cheap, easy and does not require high tech machineries and capital investments. Use of bamboo in housing however, has disadvantages, as it is a non-dimensional material and does not often come with uniform shape, size and age.

Considering the above-mentioned disadvantages there is however, a great opportunity to promote bamboo for the construction of houses as all the above problems can be solved by converting or processing bamboo into engineered panels. All the disadvantages of natural bamboo would naturally be mitigated once it is processed. The other great advantage of the panel is that it could be fabricated according to the standard requirement for the housing such as that of timber housing and would meet the requirements of building code.

Major advantages of bamboo prefabricated housing:

Bamboo prefabricated quality houses are relatively affordable compared to bricks or stone made concrete houses. These houses are environment friendly and have better earthquakes resistance (The lab test conducted in India supported by DFID has shown that bamboo house can easily stand 7-rector scale of earthquake) and they have good insulation characteristics.

The experience from the INBAR/ TNC bamboo housing project revealed that a 30 square meter bamboo house would save about 10 cubic meter of timber. In more general terms: building one small two-room house with bamboo rather than wood could already save at least one big mature tree. A research conducted in Costa Rica revealed that only 70 hectares of bamboo plantation are sufficient to build 1,000 bamboo houses per year. If these houses were built with timber, 500 hectares of natural forests would be destroyed every year.

Studies show that processing of bamboo requires only 1/ 8 of the energy that concrete needs to create a building material of the same capacity. In comparison to steel, bamboo needs only 1/ 50 the amount of energy for processing. Bamboo has a zero waste as all the parts of the bamboo can be utilized efficiently. Bamboo dust has been used for making particleboard and insulation brick. These houses would contribute to the society by providing affordable but quality prefabricated bamboo houses to poor and homeless people. These houses require minimum time to construct and install (minimum of one to maximum of three months) hence, can be effectively used for relief purposes in the times of natural disaster.

Bamboo in Bhutan:

The unprecedented construction boom in Bhutan emerge a great pressure on the local forestry resources. As the demand of timber increase in construction market, the supply continues to diminish and result in price hike. Sustainable alternative to the timber is bamboo which grows naturally in Bhutan because of the country's largely undisturbed forests and the limited agriculture practiced in areas where bamboo proliferates (Table 13).

Bhutanese bamboo is principally of Himalayan and Chinese-Japanese origins, with some Southeast Asian and South Indian contributions. Bhutan has 15 genera and 31 species of bamboo. Possibly as many as 50 more species exist, that produce strong, lightweight, flexible poles excellent for use in earthquake-resistant building structures, bamboo has traditionally been overlooked as a material for local construction.

Table 13 : Bamboo in Bhutan

Botanical name	Local name	Distribution	Parts used
Arundinaria spp.	Maling bans	Chimithangka and Thimphu Selephu/Paro Diafam, Bhangtar, Nganglam, Deothang/ Samdrup Jongkha	Stems Leaves
Arundinaria maling	Hima	Begana, Helela, Lamperi/Thimphu	Stems
Bambusa spp.	Bhalu bans	Sarpang, Samdrup Jongkha Samtse	Stems
Dendrocalamus spp.	Mal bans/Choya bans	Sarpang Zhemgang Samdrup Jongkha Pemagatshel	Stems
Dendrocalamus stricta	Bejuli bans	Sarpang	Stems

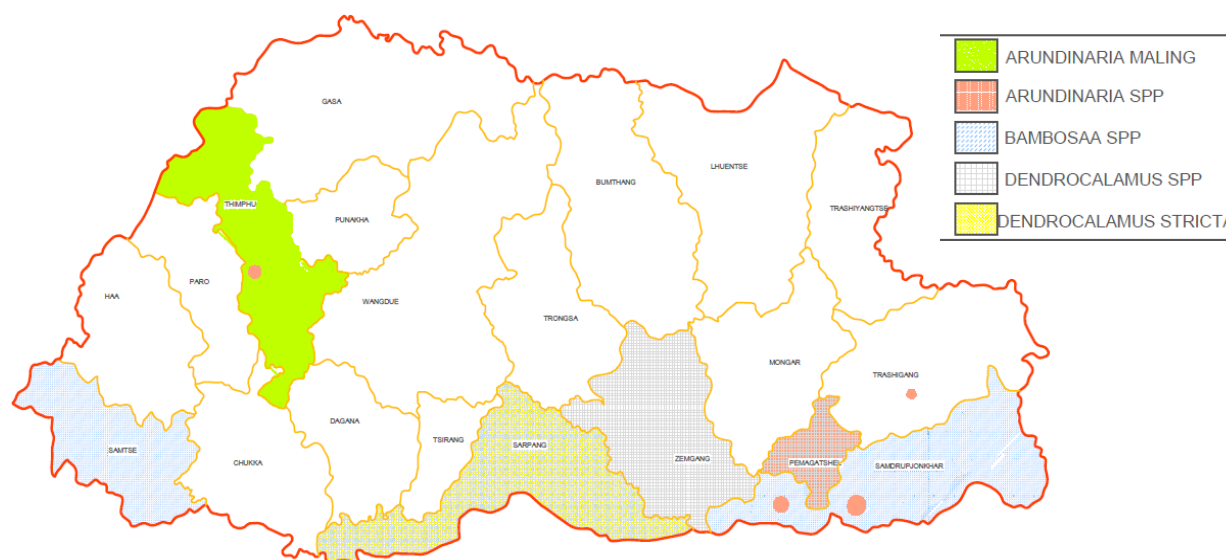


Figure 22 : Map showing areas with different species of bamboo in Bhutan

Bhutan's Ministry of Agriculture and Forests Joined INBAR in 2009 and is working to promote the use of bamboo as a sustainable alternative to timber. In Dec 2011 the first bamboo demonstration house was built in Tingtibi, Bhutan. Recently, the Ministry has signed with INBAR to implement a new 2-year Common Fund for Commodities (CFC)-funded pilot project on bamboo value chain development for construction products.

Bhutan already has a comprehensive *bamboo harvesting guidelines* in place given the likelihood of its increasing demand (National Forest Policy Goal, Royal Government of Bhutan) which further strengthens the basis to promote this as one of the alternative building materials

CASE STUDY

Name of Project	Residence of the Tingtibi Community Chief
Name of Developer / Owner / Promoter	Royal Government of Bhutan
Name of Architect / Design Firm	INBAR
Project Completion	2011
Site Area	
Built Up Area	100 Sq.m
Contact Detail	www.inbar.in

1. The new structure uses local bamboo as the framework of the house and for many of the walls, with timber still used for some joints, whilst the use of traditional adobe walling and a thatched roof ensures that all materials, except the cement used in the foundations, were sourced locally.



The house uses approximately 25.5m³ less wood than an equivalent timber-framed home, and is nearly half the price, at a cost of US\$140/ m².

Source: <http://www.inbar.int/2012/01/bambooconstruction-bhutan/>

2. The house is built to last, with an expected life-span of at least 20 years, and its earthquake resistance has already been proven — immediately after completion in September 2011 the house withstood shocks from an earthquake in nearby Sikkim, India, without suffering any damage.

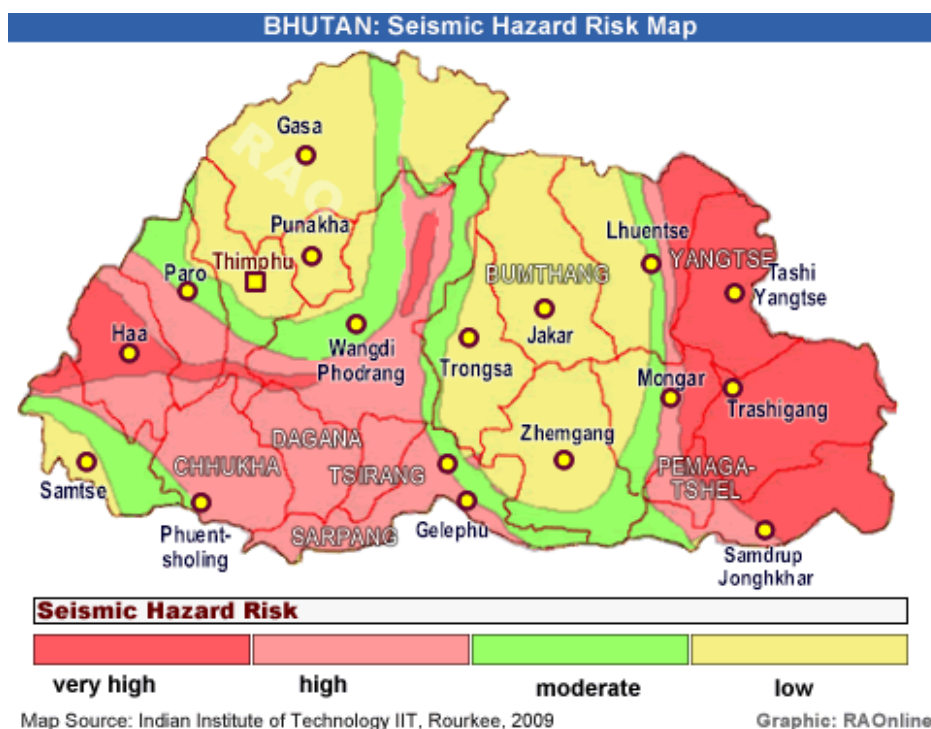
3. This innovative project has shown that bamboo buildings clearly have the potential to help Bhutan develop sustainably, and as a result, the government now plans to construct three more bamboo structures in 2012 with INBAR's support.
4. Areas where bamboo is readily available, such construction types should be promoted by the local authorities.

Earthquake-Resistant Construction:

The most dangerous natural hazard which damages buildings and man-made structures is Earthquake. Parameters such as intensity, duration and frequency content of ground motion, geological and soil condition, quality of construction etc., signifies the earthquake damage.

To construct Earthquake resistance building which will not get damage in Strong earthquake such buildings will be too robust and also too expensive. Instead, the engineering intention is to make buildings earthquake resistant; such buildings resist the effects of ground shaking, may get damaged severely but would not collapse during the strong earthquake thus ensuring the safety of people in earthquake and thereby a disaster is avoided.

Geo-physically, Bhutan is located in one of the most seismically active zones in the world. its proximity to the North-eastern parts of India, which is in the 'most active' seismic Zone V (according to Bureau of Indian Standards), indicates that the majority of Bhutan is either in Zone IV, according to the seismic hazard map of Bhutan, drawn by IIT Roorkee, India.



Earthquake effects on a structure:

Structural elements such as walls, columns and beams, are only bearing the weight of the building and the live load under normal conditions. Mostly compression forces for the walls and columns and vertical bending for the beams.

The earthquake design philosophy may be summarized as follows:

- **Minor:** Under minor but frequent shaking, the main members of the building that carry vertical and horizontal forces should not be damaged; however building parts that do not carry load may sustain repairable damage.
- **Moderate:** Under moderate but occasional shaking, the main members may sustain repairable damage, while the other parts of the building may be damaged such that they may even have to be replaced after the earthquake; and
- **Strong:** Under strong but rare shaking, the main members may sustain severe (even irreparable) damage, but the building should not collapse.

Thus, after minor shaking, the building will be fully operational within a short time and the repair costs will be small. And, after moderate shaking, the building will be operational once the repair and strengthening of the damaged main members is completed. But, after a strong earthquake, the building may become dysfunctional for further use, but will stand so that people can be evacuated and property recovered.

Based on the above philosophy and the earthquake hazard of the country, there are regulations provided by respective local authorities to be followed.

- Strict enforcement of the structural guidelines as applicable for all planned settlements should be followed. In case, it is observed that there are not enough structural engineers available in the country, capacity enhancement program may be undertaken.
- Guidelines for rural construction in stone masonry prepared by the Standards & Quality Control Authority should be referred to and widely disseminated in non-planned settlements. The guidelines is an excellent compendium providing simple techniques and well established construction practices to improve the earthquake resisting capacity of non-engineered stone masonry buildings.
- For further outreach, tip sheets in the local language with a lot of sketches and training programs at the Geog level may be introduced for wider adoption.

SECTION 8: IMPLEMENTATION

The key to the success of the proposed guidelines is in successful implementation. Effective implementation of any initiative is possible only after undertaking the required awareness generation measures, training & capacity building activities and also by initiating some specific integration with the existing policy/ Rules framework in tune with the overall objectives of the initiative. Some of these suggested implementation strategies are as under:

- Wherever applicable, integration with the Bhutan Building Rules 2002 and the recently introduced Rural Construction Rules 2013 for non-planned settlements of Bhutan.
- Integration of guidelines with all the DCR for existing and new towns
- Micro-hazard zone mapping to be taken up on a priority basis by the respective Ministry in association with the MoWHS given the highly seismic nature of the entire country.
- Species (pref. fast growing) which may be used for preventing soil erosion is required. Such a list may be requested from the Department of Agriculture & Forestry
- List of native species of trees, shrubs and grass may be attached with relevant Building rules. Such a list may be requested from the Department of Agriculture & Forestry.
- Slopes identification for all areas (other than the places for which structural plans with such details are available) should be taken up for identification of areas where restricted/ conditional construction may be allowed.
- Existing vegetation format may be given as additional clause with the set of documents required for submission-MoWHS (for all planned and non-planned areas)
- Solar Water Heating may be mandated for typologies such as hotels; for others may be incentivised/ promoted by various means (MoWHS and Department of Renewable Energy should jointly work on the implementation strategy)
- Solar Photovoltaics-MoWHS should work with Department of Renewable Energy to devise strategies for implementation
- Water quality standards for flushing and other non-potable applications may be taken up by NEC for wider adoption and implementation of water related guidelines
- Supply chain systems- The entire supply chain for products such as Solar water heaters, SPV, alternative building materials, thermal insulation, high performance glass, etc. need to be developed in close coordination with various departments and ministries.

- Given the high susceptibility of the entire country to various climate change induced extreme events, each Dzongkhag need to prepare resilience plan at settlement level
- Strict enforcement plan (may use incentives/ disincentives/ or other policy tools) is essential
- There is a strong need for a separate Act on Planning as practiced in other countries so that overall better implementation is achieved
- Right to adequate housing should not contradict with overall environmental considerations and should go hand in hand
- All environmentally sensitive areas and features should be protected and measures to avoid, minimize or mitigate environmental impacts of the proposed development (especially in the case of large projects, townships, dams, industries, etc.) should be taken up.
- For mapping of areas which are extremely fragile, it is recommended that organisations like NEC in association with Ministry of Works and Human Settlement prepare such spatial maps
- The approved list of construction material should be regularly updated and as far as possible integrate region specific local materials as well such as the ones discussed in the section on Building Materials.
- Dissemination of the use of tools and techniques on use of such local alternative materials among the various stakeholders engaged in the construction sector and also among the users is equally important.
- **Communication plan:** An overarching marketing and communication strategy may be evolved by the Ministry as a whole and prioritized action plans can be taken up during the current Five-Year Plan. Communication and dissemination plan separately for implementers, building professionals and end users is required.
- **Integration with existing Education system:** The curriculum of architectural, planning and engineering programs in the country do not have any focus on integrated design, green design and environmentally conscious design. As a result, implementation of any such guidelines becomes more challenging. It is therefore, strongly recommended to make necessary changes in the curriculum of the ongoing engineering, planning and architectural courses.
- **Skill upgradation for construction workers** is also strongly recommended given the demand-supply gap and also to promote more jobs for Bhutanese.
- **Co-ordination:** Co-ordination amongst stakeholders at the design stage and during the construction stages of projects is very important from environmental sustainability perspective which is currently missing and needs to be worked upon through planned capacity building and awareness programs.

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Annexure:

Need for promoting adequate spacing between buildings

Also known in planning terminology as ‘setbacks’, spacing between buildings is an important component. They serve many purposes. ‘Setback’ is the required distance that a building must be located away from the streets, easements, and other structures including buildings. Setbacks allow a certain measure of privacy between neighbors, provide space for light and air circulation, and provide open space for landscaping and recreational use. They also provide distance between neighbors to mitigate noise and odors. It is particularly important in the context of Bhutan to allow for proper ventilation to mitigate the pollutants from kitchen and other spaces, given the fact that a lot of fuelwood is used for fodder cooking and space heating.

Spacing between buildings is also important to allow for adequate daylight in living spaces of a dwelling. Along with the importance of energy, studies have demonstrated the non-energy related benefits of daylighting. Even if a building is designed well for daylight, if there is inadequate spacing between buildings, not many benefits can be availed of daylight.

Humans are affected both psychologically and physiologically by the different spectrums provided by the various types of light. These effects are the less quantifiable and easily overlooked benefits of daylighting. It is well recognised that good glarefree daylight leads to improved mood, enhanced morale, lower fatigue, improved productivity in workspaces and reduced eyestrain. One of the important psychological aspects from daylighting is meeting a need for contact with the outside living environment (Robbins 1986).

Wavelengths of light help control the human body’s chemistry. Many functions, including the nervous system, circadian rhythms, pituitary gland, endocrine system, and the pineal gland are affected by different wavelengths of light. Studies have shown that light can help cure rickets, osteomalacia, and Seasonal Affective Disorder (SAD).

Given the aforementioned advantages of providing certain spacing between buildings, it is recommended to be observed to the extent possible.

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