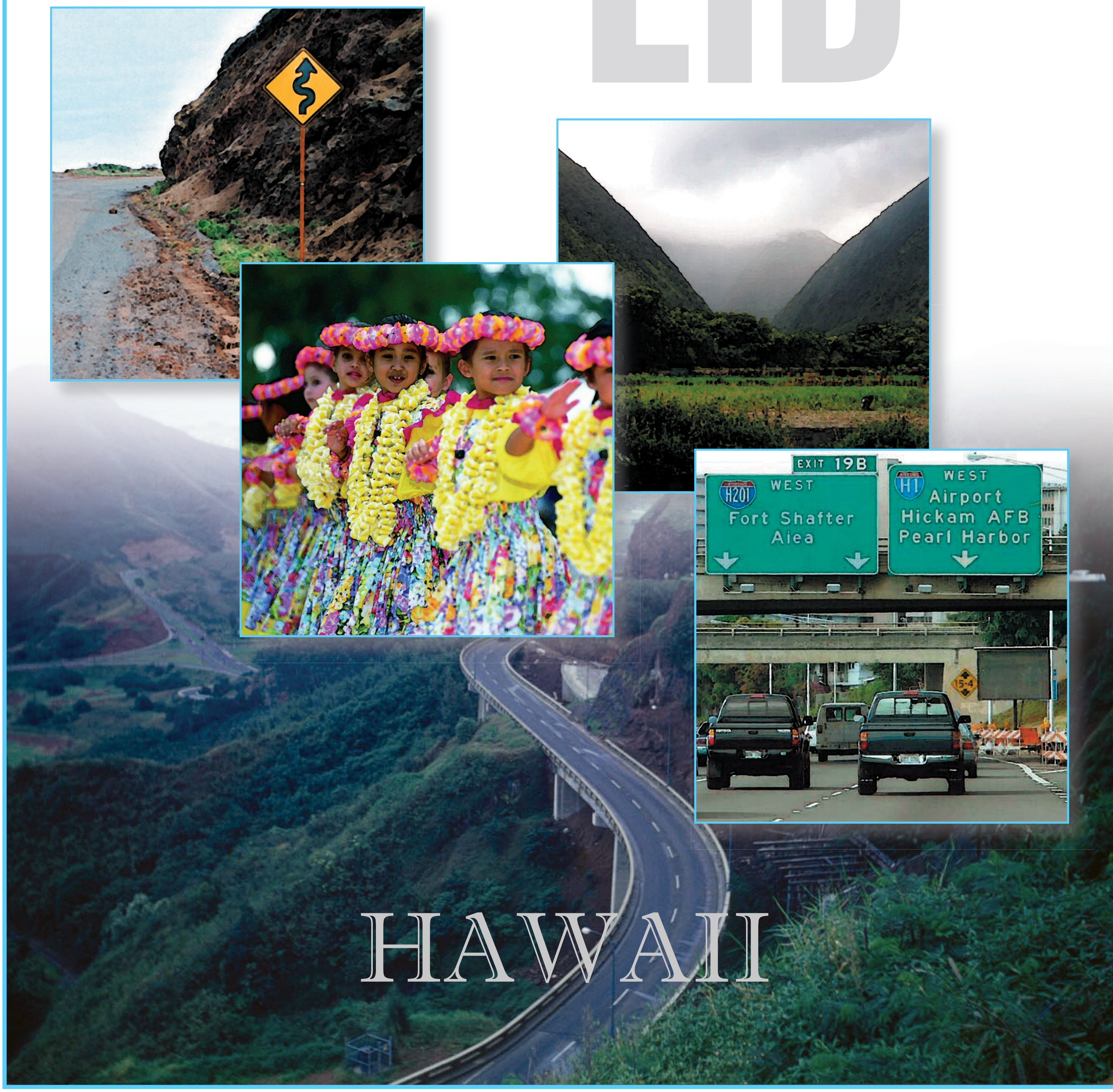
LOW IMPACT DEVELOPMENT
A PRACTITIONER'S GUIDE

LID

June 2006



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Agenda

Low Impact Development
A Practitioner's Guide

8:00	Registration	
8:30	Welcome/Introductions	Laura Thielen
8:45	Introduction to LID Better Site Design Principles The Value of LID vs. Conventional Design Effectiveness Cost Comparisons	Mark Nelson - Maui, Kauai Scott Horsley - Hawaii, Oahu
9:30	Road Design – How Much is Enough? Introduction to the Issue Appropriate Design Standards Case Studies – Precedents from Other States	Michelle West - Maui, Kauai Scott Horsley - Hawaii, Oahu
10:00	Break	
10:15	Stormwater Management and LID Design Criteria for Hawaii BMP Selection and Design Case Studies Operation and Maintenance Requirement Incorporating LID into Design Codes	Michelle West - Maui, Kauai Rich Claytor - Hawaii, Oahu
11: 30	Wastewater Management and LID Hawaii Wastewater Management Requirements Wastewater Impacts on Drinking and Coastal Waters Alternative Wastewater Management Options Case Studies	Mark Nelson - Maui, Kauai Rich Claytor - Hawaii, Oahu
12:00	Overview of Available LID References	
12:15	Adjourn	

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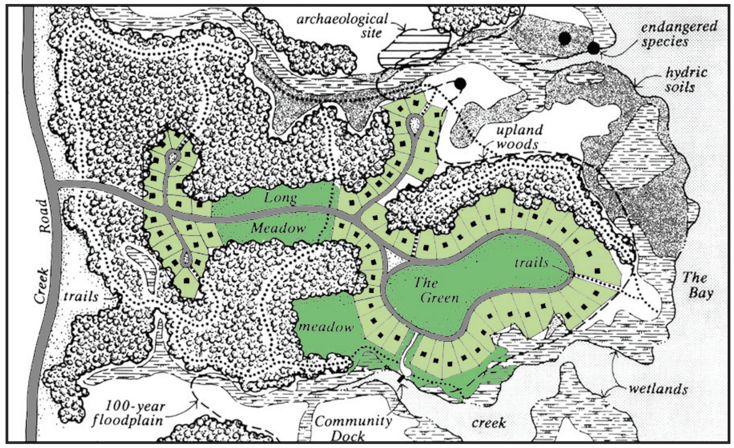
1 Overview of Low Impact Development Principles



As research, technology, and information transfer have improved over recent years, alternative approaches are being sought by the public and regulatory boards to reduce the environmental impacts from new development and redevelopment. Developers and designers are also seeking alternatives to expedite permitting processes, reduce construction costs, reduce long-term operation and maintenance costs, and increase property values. Low Impact Development sometimes referred to as "Low Impact Design" (LID) has emerged as an effective way to address these issues.

LID is a relatively new comprehensive planning and engineering design approach that surfaced in the early 90s. Since then, much has been learned about which techniques work in the field and which do not. The ultimate goal of this LID workbook is to compile this hard-won knowledge and experience into a single comprehensive handbook that is useful to planners, engineers, and the regulating community in order to protect the vital water resources of the Hawaiian Islands.

The purpose of this chapter is to provide an introduction to LID, as well as guidance to plan for and implement LID practices for new development and redevelopment projects in the State of Hawaii. While reducing the impacts from development may be achieved through both regulatory and non-regulatory techniques, this chapter focuses on the site-level planning and design tools available to the development community. **Chapters 2 - 4** provide further detail on road design criteria, stormwater management, and wastewater management. LID resources are included in **Chapter 5** for more information on these topics.

1.1 The Problem with Conventional Design

For the purposes of this chapter, Conventional Design can be viewed as the style of suburban development that has evolved over the past 50 years. This development pattern, based on conventional zoning codes, often results in sprawl with developments associated large lot areas, loss of natural areas, and alteration of hydrologic systems. Too often, the development process begins with the clearing and leveling of the entire parcel. The conventional developments that follow commonly contain wide roads, monolithic parking lots, segregated land uses, enclosed drainage systems for stormwater/wastewater conveyance, and large "hole-in-the-ground" detention basins. The large impervious areas prevent water from infiltrating into the ground (which normally replenishes groundwater supplies and supports nearby wetlands and streams with baseflow) and quickly convey polluted runoff into nearby water bodies. Conventional landscaping of these developments brings additional concerns including the introduction of non-native plants, use of herbicides, pesticides and fertilizers, and excessive water consumption.

1.2 Definition of LID

LID is defined as a more sustainable land development pattern than the conventional method currently used in most areas. It incorporates a suite of landscaping and design techniques known as "Better Site Design" that attempt to maintain the natural, pre-development hydrology of a site and the surrounding watershed. An important LID principle is the idea that stormwater is not merely a waste product to be disposed of, but rather that rainwater is a resource. LID also integrates a range of structural best management practices (BMPs) for road design and stormwater and wastewater management systems that minimize environmental impacts. These are discussed in more detail in **Chapters 2-4**.

1.3 Goals of LID

The aim of LID is to reduce the environmental impact "footprint" of the site while retaining and enhancing the owner/developer's purpose and vision for the site. Many of the LID concepts employ non-structural on-site treatment that can reduce the cost of infrastructure while maintaining or even increasing the value of the property relative to conventional designed developments. The goals of LID include:

- Prevent environmental impacts rather than having to mitigate for them;
- Manage water (quantity and quality) as close to the source as possible and minimize the use of large or regional collection and conveyance;
- Preserve natural areas, native vegetation and reduce the impact on watershed hydrology;
- Use natural drainage pathways as a framework for site design;
- Utilize less complex, non-structural methods for stormwater/wastewater management that are lower cost and lower maintenance than conventional structural controls; and
- Create a multifunctional landscape.

1.4 Benefits of LID

LID provides important benefits to the local municipality, the developer, and the general public. More concentrated (cluster) design, with less impervious area and smaller infrastructure (stormwater drainage and other utilities), means significant construction cost savings to developers. Less impervious surface creates less surface runoff, which will decrease the burden to municipal drainage infrastructure. These techniques also reduce nonpoint source pollution to drinking water supplies, recreational waters, and wetlands, saving future expenditures for restoration of valuable water resources. Other LID benefits include:

- Reduced long-term operation and maintenance costs;
- Increased property values;
- Easier compliance with wetland and other resource protection regulations;
- More open space for recreation;
- More pedestrian friendly neighborhoods;
- Protection of sensitive forests, wetlands, and habitats; and
- More aesthetically pleasing and naturally attractive landscape.

1.5 LID Planning Process

Site design should be done in unison with the design and layout of stormwater and wastewater infrastructure in attaining management and land use goals. The LID process utilizes a three-step process as follows:

1. Avoid the Impacts – Preserve Natural Features and use Conservation Design Techniques.
2. Reduce the Impacts – Reduce Impervious Cover.
3. Manage the Impacts – Utilize Natural Features and Natural Low-Impact techniques to manage stormwater.

The first step in the planning and design process is to avoid or minimize disturbance by preserving natural areas or strategically locating development based on the location of resource areas and physical conditions at a site. Resources can include drinking water supply areas, streams/rivers, wetlands, coral reefs, sensitive habitat areas and scenic views, all of which should be set aside and preserved. Constraints include poor soils that cannot support septic systems and steep slopes which make construction difficult and expensive. The mapping of these areas results in "building envelopes," areas which can support development economically and ecologically.

Once sensitive resource areas and site constraints have been avoided, the next step is to minimize the impact of land alteration by reducing impervious areas. Finally, for the areas that must be impervious, alternative and "natural-systems" stormwater management techniques are chosen as opposed to the more routine structural, "pipe-to-pond," approach.

1.6 LID Categories

Stormwater LID practices and techniques covered in this chapter are grouped into the following three categories:

Preservation of Natural Features and Conservation Design: Preservation of natural features includes techniques to foster the identification and preservation of natural areas that can be used in the protection of water resources. *Conservation Design* includes laying out the elements of a development project in such a way that the site design takes advantage of a site's natural features, preserves the more sensitive areas, and identifies any site constraints and opportunities to prevent or reduce impacts.

Reduction of Impervious Cover: Reduction of Impervious Cover includes methods to reduce the amount of rooftops, parking lots, roadways, sidewalks and other surfaces that do not allow rainfall to infiltrate into the soil, in order to reduce the volume of stormwater runoff, increase groundwater recharge, and reduce pollutant loadings generated from a site.

Utilization of Natural Features and Source Control for Stormwater Management: Utilization of Natural Features for Stormwater Management includes design strategies that use natural features to help manage and mitigate runoff, rather than structural stormwater controls. Source Control for Stormwater Management includes elements to mitigate or manage stormwater in a more natural manner.

1.7 LID Best Management Practices

Table 1.1 lists the specific LID BMPs and techniques for each of the three categories, followed by a description of each practice.

Table 1.1 LID General Categories and Specific BMPs

Preservation of Natural Features and Conservation Design
1. Preservation of Undisturbed Areas 2. Preservation of Buffers 3. Reduction of Clearing and Grading 4. Locating Sites in Less Sensitive Areas 5. Open Space Design
Reduction of Impervious Cover
6. Roadway Reduction* 7. Sidewalk Reduction* 8. Driveway Reduction 9. Cul-de-sac Reduction 10. Building Footprint Reduction 11. Parking Reduction
Utilization of Natural Features and Source Control for Stormwater Management
12. Vegetated Buffer/Filter Strips 13. Open Vegetated Channels** 14. Bioretention and Rain Gardens** 15. Infiltration** 16. Rooftop Runoff Reduction Mitigation 17. Stream Daylighting for Redevelopment Projects 18. Tree Planting

* These practices are described in further detail in **Chapter 2**.
These practices are described in further detail in **Chapter 3.

<u>Practice #1 – Preservation of Undisturbed Areas</u>: Important natural features and areas such as undisturbed forested and native vegetated areas, natural terrain, riparian corridors, wetlands and other important site features should be delineated and placed into permanent conservation areas.

- Delineate and define natural conservation areas before performing site layout and design; and
- Ensure that conservation areas and native vegetation are protected in an undisturbed state through the design, construction and occupancy stages.

Practice #2 – Preservation of Buffers: Naturally vegetated buffers should be defined, delineated and preserved along perennial streams, rivers, coastlines, and wetlands.

- Delineate and preserve naturally vegetated riparian buffers (define the width, identify the target vegetation, designate methods to preserve the buffer indefinitely);
- Ensure that buffers and native vegetation are protected throughout planning, design, construction and occupancy; and
- Consult local planning authority for minimum buffer width and/or recommended width.

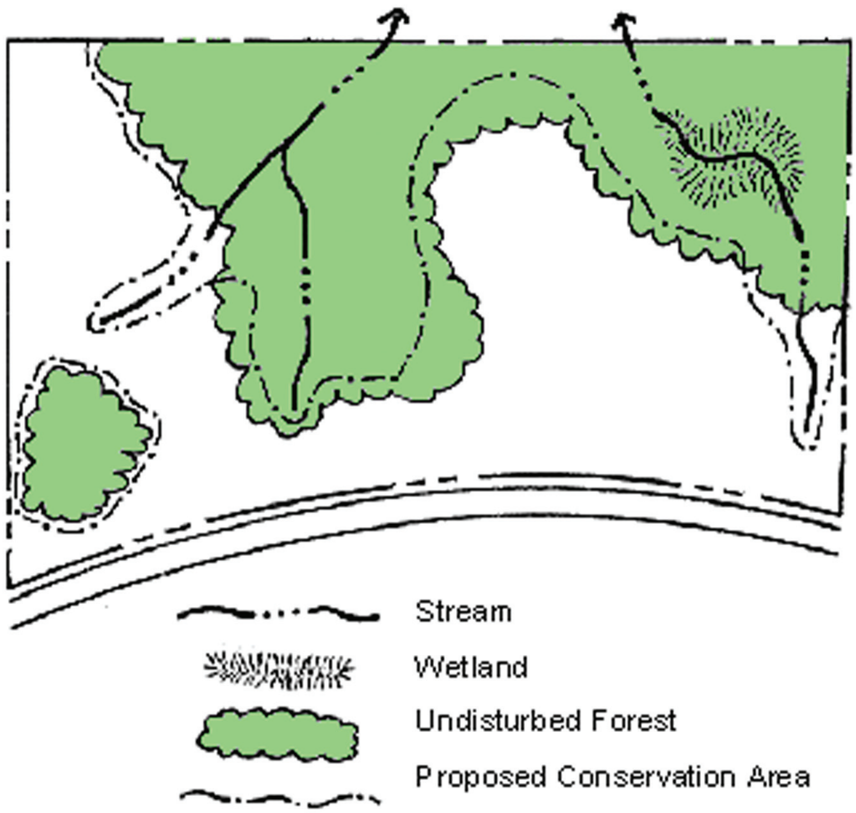


Figure 1.1 Example of Natural Resource Inventory Plan.

(Source: Georgia Stormwater Manual, 2001)

Practice #3 – Reduction of Clearing and Grading: Clearing and Grading of the site should be limited to the minimum amount needed for the development function, road access, and infrastructure (e.g. utilities, wastewater disposal, stormwater management). Site foot-printing should be used to disturb the smallest possible land area on a site.

- Restrict clearing to the minimum area required for building footprints, construction access, and safety setbacks;
- Establish limits of disturbance for all development activities;
- Use site foot-printing to minimize clearing and land disturbance;
- Limit site mass grading approach; and
- Use alternative site designs that use open-space or "cluster" developments.

Practice #4 – Locating Sites in Less Sensitive Areas: Development sites should be located to avoid sensitive resource areas such as floodplains, steep slopes, erodible soils, wetlands, mature forests and critical habitat areas. Buildings, roadways, and parking areas should be located to fit the terrain and in areas that will create the least impact.

- Ensure all development activities do not encroach on designated floodplain and/or wetland areas;
- Avoid development on steep slope areas and minimize grading and flattening of hills and ridges;
- Leave areas of porous or highly erodible soils as undisturbed conservation areas;
- Develop roadway patterns to fit the site terrain and locate buildings and impervious surfaces away from steep slopes, drainageways and floodplains; and
- Locate site in areas that are less sensitive to disturbance or have a lower value in terms of hydrologic function.

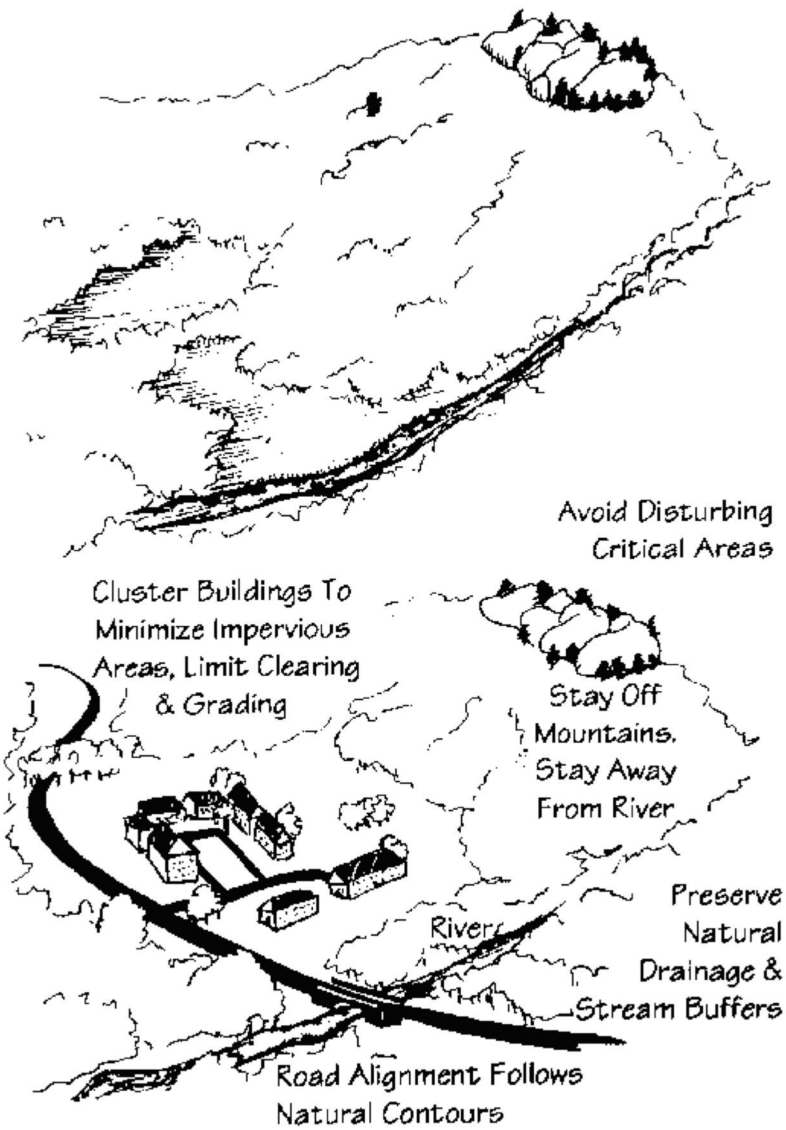


Figure 1.2 Fit the design of a site to the terrain and natural features.

Practice #5 – Open Space Design: Open space site designs (also referred to as conservation development or clustering) incorporate smaller lot sizes to reduce Figure 1.2 Fit the design of a site to the terrain and natural features
overall impervious cover while providing more undisturbed open space and protection of water resources.

- Use a site design which concentrates development and preserves open space and natural areas of the site;
- Locate the developed portion of the cluster areas in the least sensitive areas of the site (see practice #4); and
- Utilize reduced setbacks and frontages, and narrower right-of-way widths to design non-traditional lot layouts within the cluster.

<u>Practice #6 – Roadway Reduction</u>: Roadway lengths and widths should be minimized on a development site where possible to reduce overall imperviousness (See **Chapter 2** for more detailed information on this practice).

- Consider different site and road layouts that reduce overall street length;
- Minimize street width by using narrower street designs that are a function of land use, density and traffic demand; and
- Use smaller side yard setbacks to reduce total road length.

Figure 1.3 Residential road that is much wider than necessary to accommodate residential traffic flow.

<u>Practice #7 – Sidewalk Reduction</u>: Sidewalk lengths should be minimized on a development site where possible to reduce overall imperviousness (**Chapter 2** includes more information on this practice).

- Locate sidewalks on only one side of residential streets;
- Provide common walkways linking pedestrian areas;
- Use alternative sidewalk and walkway surfaces; and
- Shorten front setbacks to reduce walkway lengths

<u>Practice #8 – Driveway Reduction</u>: Driveway lengths and widths should be minimized on a development site where possible to reduce overall imperviousness.

- Use shared driveways that connect two or more homes together;
- Use alternative driveway surfaces such as permeable pavers (see Figure 1.5); and
- Use smaller lot front building setbacks to reduce total driveway length.

Practice #9 – Cul-de-sac Reduction: Minimize the number of cul-de-sacs and incorporate landscaped areas to reduce their impervious cover. The radius of a cul-de-sac should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should also be considered.

- Reduce the radius of the turnaround bulb or consider alternative cul-de-sac design, such as "tee" turn-a-rounds or looping lanes;
- Apply site design strategies that minimize dead-end streets; and
- Create a pervious island or a stormwater bioretention area in the middle of the cul-de-sac to reduce impervious area.

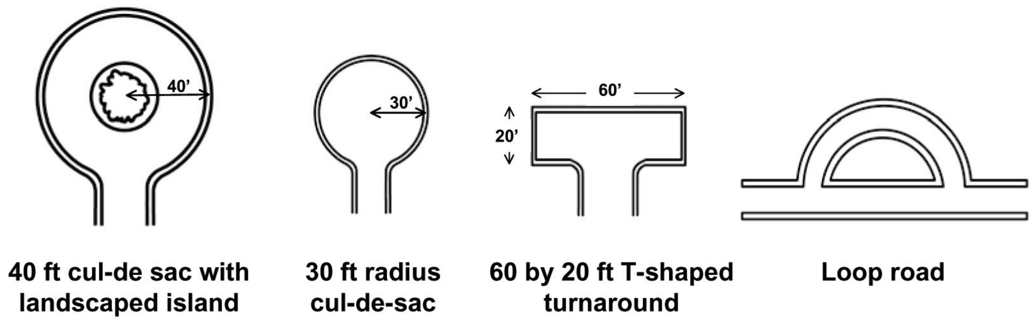


Figure 1.4 Turnaround Options for Residential Streets.

(Source: Adapted from Schueler, 1995)

Practice #10 – Building Footprint Reduction: The impervious footprint of residences and commercial buildings can be reduced by using alternate or taller buildings while maintaining the same floor to area ratio.

- Use alternate or taller building designs to reduce the impervious footprint of buildings;
- Consolidate functions and buildings or segment facilities to reduce footprints of structures; and
- Reduce directly connected impervious areas.

Practice #11 – Parking Reduction: Reduce the overall imperviousness associated with parking lots by eliminating unneeded spaces, providing some compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, utilizing multi-storied parking decks, and using porous paver surfaces or porous concrete in overflow parking areas where feasible.

- Reduce the number of unneeded parking spaces by examining minimum parking ratio requirements, and set a maximum number of spaces;
- Reduce the number of unneeded parking spaces by examining the site's accessibility to mass transit;
- Minimize individual parking stall dimensions;
- Examine the traffic flow of the parking lot design to eliminate unneeded lanes / drive aisles;
- Consider parking structures and shared parking arrangements between non-competing uses;
- Use alternative porous surface for overflow areas, or in main parking areas if not a high traffic parking lot;

- Use landscaping or vegetated stormwater practices in parking lot islands; and
- Provide incentives for compact cars.

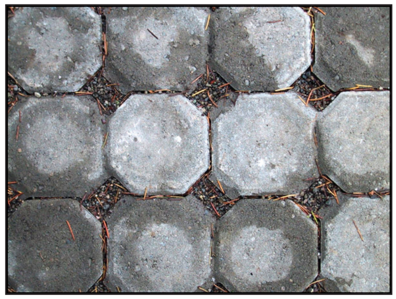


Figure 1.5 Examples of Permeable Pavers.

<u>Practice #12 – Vegetated Buffer/Filter Strips</u>: Undisturbed natural areas such as forested conservation areas and stream buffers, or vegetated filter strips, can be used to treat and control stormwater runoff from some areas of a development project. (Figure 1.6)

- Direct runoff towards buffers and undisturbed areas using sheet flow or a level spreader to ensure sheet flow;
- Utilize natural depressions for runoff storage;
- Direct runoff and nature of runoff (sheet flow vs. shallow concentrated flow) to buffer/filter strip areas;
- Examine the slope, soils and vegetative cover of the buffer/filter strip; and
- Disconnect impervious areas to these areas.

Figure 1.6 Use of a Grassed Filter Strip.

Practice #13 – Open Vegetated Channels: The natural drainage paths of a site, or properly designed and constructed vegetated channels, can be used instead of constructing underground storm sewers or concrete open channels. Where density, topography, soils, slope, and safety issues permit, vegetated open channels can be used in the street right-of-way to convey and treat stormwater runoff from roadways.

- Preserve natural flow paths in the site design;
- Direct runoff to natural drainage ways, ensuring that peak flows and velocities will not cause channel erosion;
- Use vegetated open channels (enhanced wet or dry swales or grass channels) in place of curb and gutter, and pipes, to convey and treat stormwater runoff; and
- Ensure runoff volumes and velocities provide adequate residence times and non-erosive conditions (i.e. use of check dams).

Practice #14 – Bioretention and Rain Gardens: Provide stormwater treatment for runoff from impervious surfaces using bioretention areas or rain gardens that can be integrated into required landscaping areas and traffic islands.

- Integrate bioretention into a parking lot or roadway design;
- Integrate bioretention, or rain gardens, into on-lot residential designs;
- Closely examine runoff volumes and velocities to ensure runoff enters bioretention in a distributed manner and in a non-erosive condition;
- Ensure the bioretention has proper pre-treatment;
- Carefully select the landscaping materials required; and
- Works well as a retrofit or in redevelopment projects.

Practice #15 – Infiltration: Utilize infiltration trenches, basins, or leaching chambers to provide groundwater recharge, mimic existing hydrologic conditions, and reduce runoff and pollutant export. Permeable paving surfaces may also be used where site conditions are appropriate.

- May be used for roadway or parking impervious areas if adequate pre-treatment is provided;
- Rooftop runoff may discharge directly to drywells or infiltration chambers (**Figure 1.7**);
- The site must have soils with moderate to high infiltration capacities and must have adequate depth to groundwater;
- Certain sites (i.e. pollutant hotspots) require additional pretreatment prior to infiltration;
- Use porous pavers only in low traffic areas or for pedestrian walkways/plazas; and
- Poor soils may preclude aggressive infiltration.

Figure 1.7 Dry Well.

<u>Practice #16 – Rooftop Runoff Reduction Mitigation</u>: Direct runoff from residential rooftop areas to pervious areas, lower-impact practices, or utilize "green roof" strategies to reduce rooftop runoff volumes and rates.

- Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas;
- Direct rooftop runoff to lower-impact practices such as rain barrels, cisterns, drywells, rain gardens, or stormwater planters; and
- Utilize "green roofs" (specially designed vegetated rooftops) to reduce stormwater runoff from rooftops.

Figure 1.8 Rooftop runoff is directed to a landscaped area around this house.

<u>Practice #17 – Stream Daylighting for Redevelopment Projects</u>: Daylight previously-culverted/piped streams to restore natural habitats, better attenuate runoff, and help reduce pollutant loads where feasible and practical.

- Daylighting should be considered when a culvert replacement is scheduled;
- Restore historic drainage patterns by removing closed drainage systems and constructing stabilized, vegetated streams;
- Carefully examine flooding potential, utility impacts and/or prior contaminated sites; and
- Consider runoff pretreatment and erosion potential of restored streams/rivers.

<u>Practice #18 – Tree Planting</u>: Plant or conserve trees at new or redevelopment sites to reduce stormwater runoff, increase nutrient uptake, provide bank stabilization, provide shading, and provide wildlife habitat. Trees can be used for applications such as landscaping, stormwater management practice areas, conservation areas and erosion and sediment control.

- Conserve existing trees during construction by performing an inventory of the existing forest and identifying trees to protect;
- Design the development with tree conservation in mind, protect trees during construction, and protect trees after construction;
- Plant trees at development sites by first selecting the planting sites and then evaluate and improve the planting sites. Trees should be planted in stormwater management practices and other open spaces; and
- Tree types and locations should be chosen to withstand the constraints of the new land use and setting.

1.8 LID Case Studies

The following case studies illustrate how LID practices can be successfully incorporated into site planning. Comparisons to a conventional design approach illustrate how LID practices can be used to reduce impacts. In addition, a single-family home example is included to show how LID practices can also be utilized on a small (< 1 acre) scale.

Medium Density Residential Subdivision Case Study
A conventional residential subdivision design on a parcel is shown in **Figure 1.9a**. The entire parcel except for the subdivision amenity area (clubhouse and tennis courts) is used for lots. The entire site is cleared and mass graded, and no attempt is made to fit the road layout to the existing topography. Because of the clearing and grading, all of the existing tree cover and vegetation and topsoil are removed, dramatically altering both the natural hydrology and drainage of the site. The wide residential streets create unnecessary impervious cover and a curb-and-gutter system that carries stormwater flows to the storm sewer system. No provision for non-structural stormwater treatment is provided on the subdivision site.

A residential subdivision employing stormwater better site design practices is presented in **Figure 1.9b**. This subdivision configuration shows six (6) more lots than the conventional, while also preserving a quarter of the property as undisturbed open space and vegetation. The road layout is designed to fit the topography of the parcel, following the high points and ridgelines. The natural drainage patterns of the site are preserved and are utilized to provide natural stormwater treatment and conveyance. Narrower streets reduce impervious cover and open vegetated channels provide for treatment and conveyance of roadway and driveway runoff. Bioretention islands at the ends of cul-de-sacs also reduce impervious cover and provide stormwater treatment functions. When constructing and building homes, only the building envelopes of the individual lots are cleared and graded, further preserving the natural hydrology of the site.

Commercial Development Case Study
Figure 1.10a shows a conventional commercial development containing a supermarket, drugstore, smaller shops and a restaurant on an adjacent lot. The majority of the parcel is a concentrated parking lot area. The only pervious area is a small replanted vegetation area acting as a buffer between the shopping center and adjacent land uses. Stormwater quality and quantity control are provided by a wet extended detention pond in the corner of the parcel.

A better site design commercial development can be seen in **Figure 1.10b**. Here the same amount of retail space is dispersed on the property, providing more of an "urban-village" feel with pedestrian access between the buildings. The same number of parking spaces are broken up into separate areas, and bioretention areas for stormwater treatment are built into parking lot islands. A large bioretention area which serves as open green space is located at the main entrance to the shopping center. A larger undisturbed buffer has been preserved on the site. Because the bioretention areas and buffer provide water quality treatment, only a dry extended detention basin is needed for water quantity control.

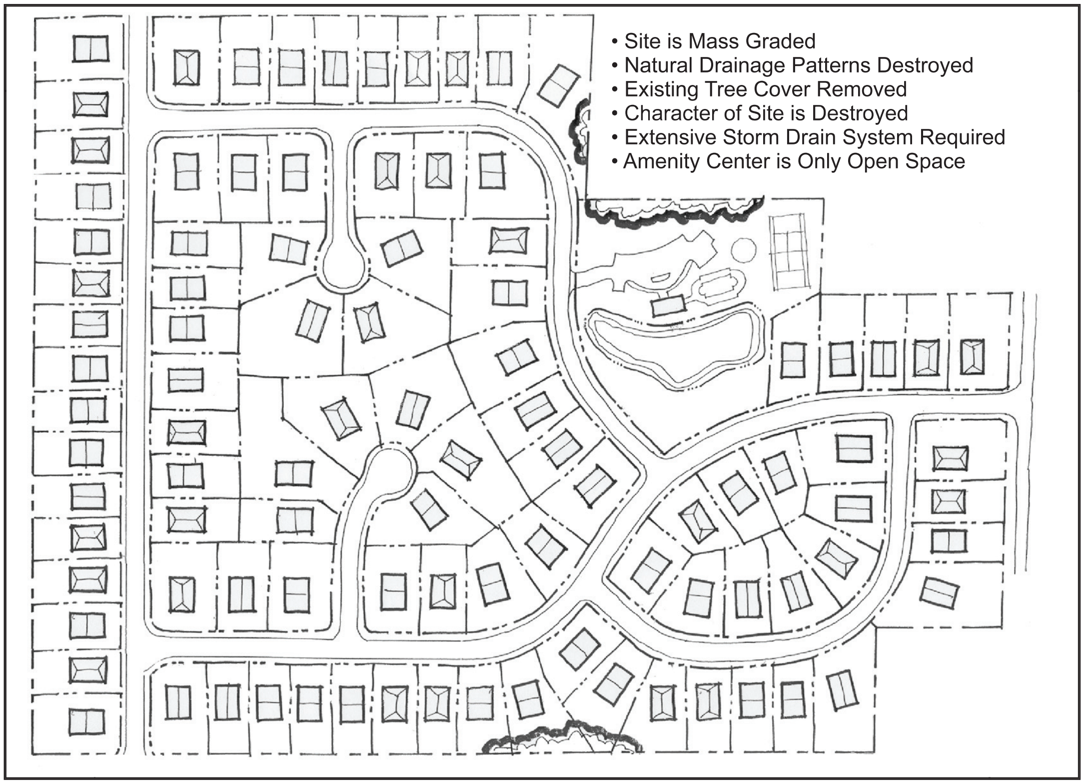


Figure 1.9a Residential Subdivision - Conventional Design.

(Source: Georgia Stormwater Manual, 2001)

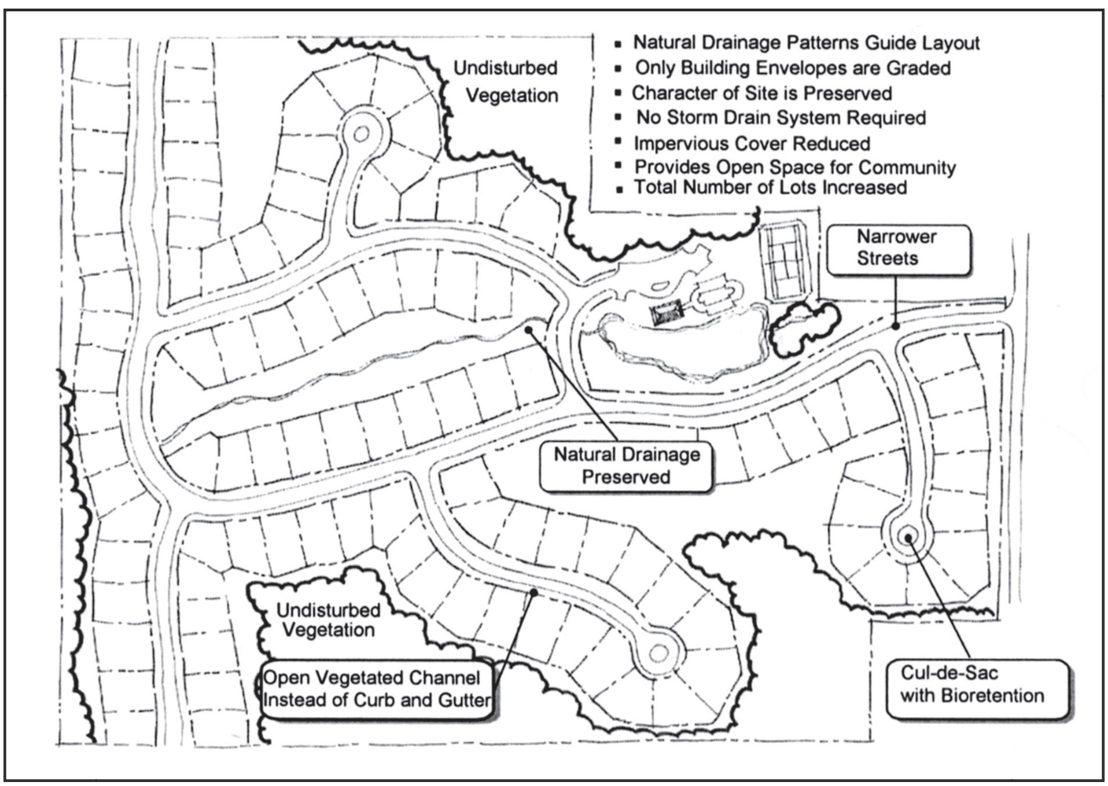


Figure 1.9b Residential Subdivision - Better Site Design.

(Source: Georgia Stormwater Manual, 2001)

***Number of lots actually increased in Better Site Design layout.**

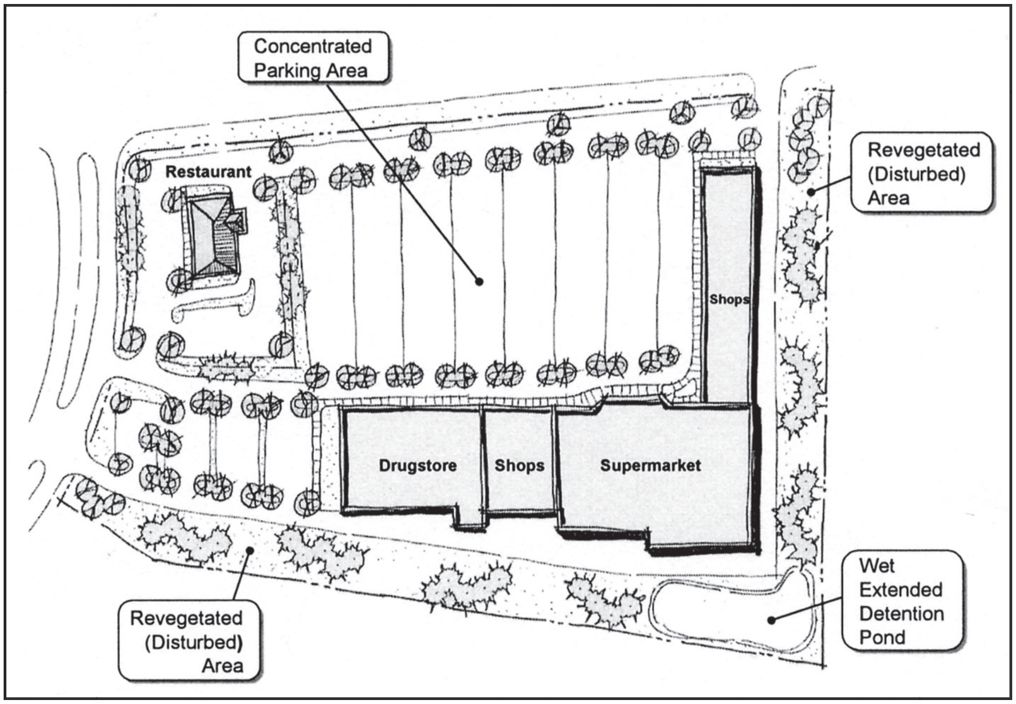


Figure 1.10a Commercial Development - Conventional Design.

(Source: Georgia Stormwater Manual, 2001)

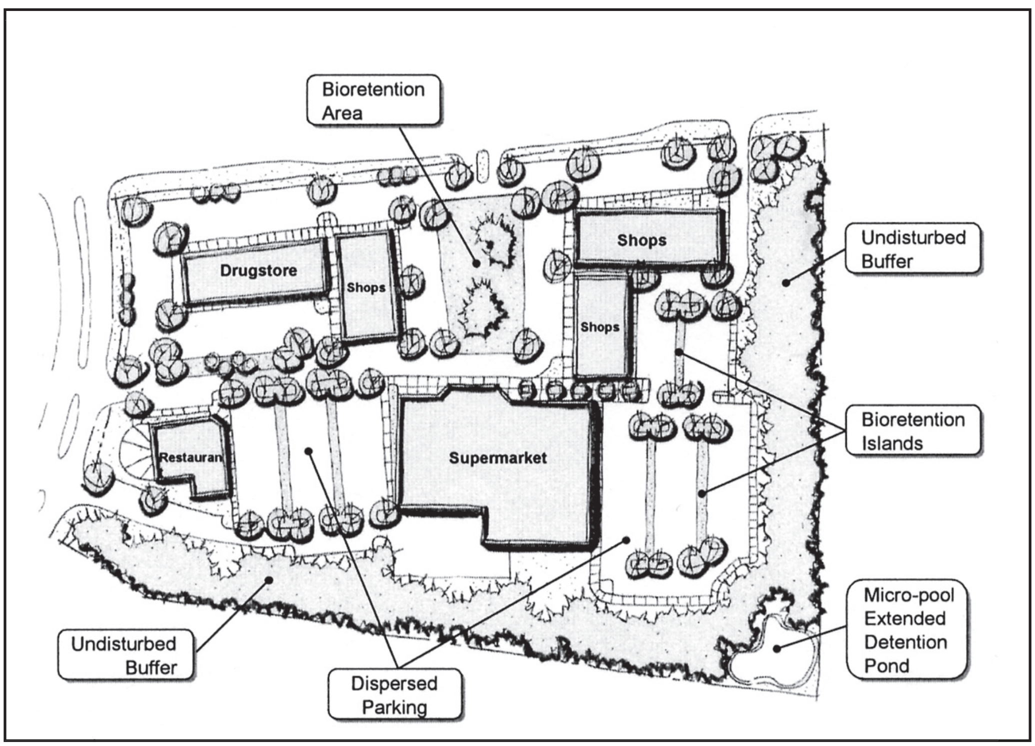


Figure 1.10b Commercial Development - Better Site Design.

(Source: Georgia Stormwater Manual, 2001)

***Number of parking lots and amount of retail space are same in both designs.**

Single-family Home Case Study
This case study represents a single-family residential site. This example (see **Figure 1.11**) focuses on a hypothetical site consisting of a ¼-acre lot. There are many structural and non-structural ways that a single-family home can incorporate LID practices. Some BMPs that could be utilized for this site are shown in **Figure 1.11** and described below.

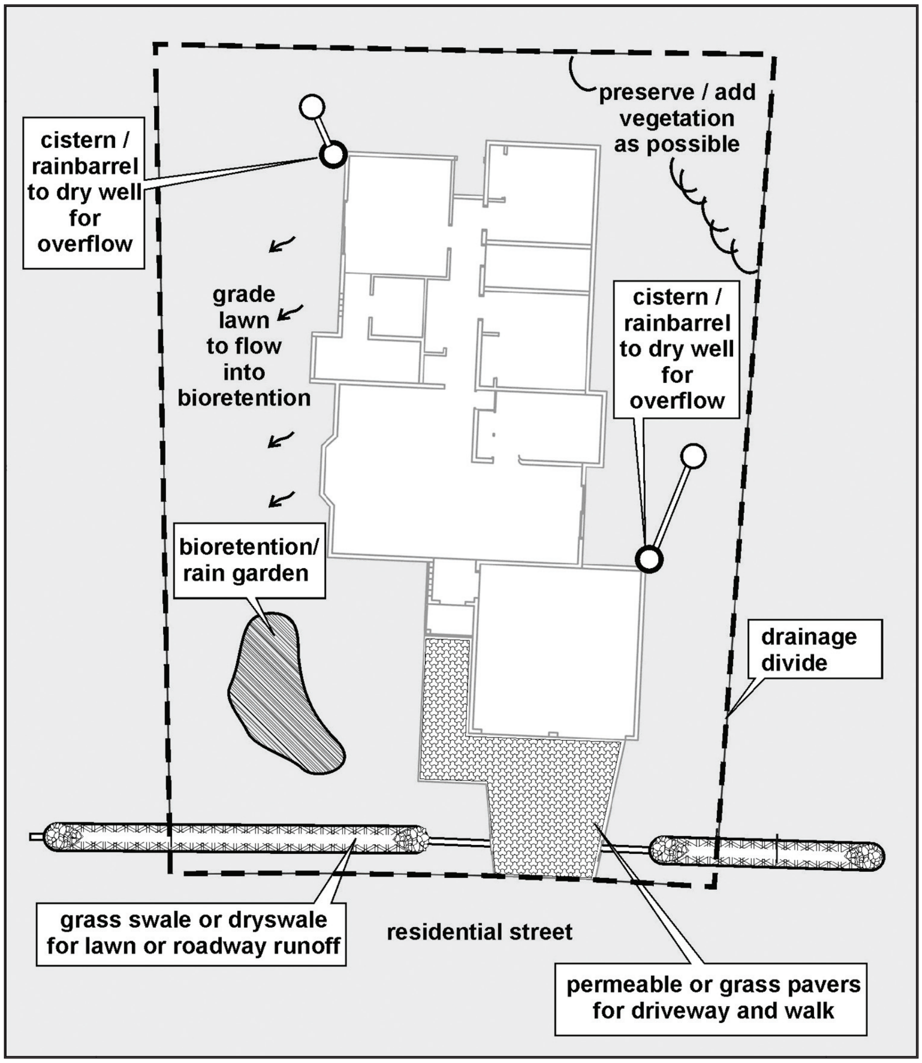


Figure 1.11 Single-family Residential Site Plan.

The impacts from this site can be reduced by using a cistern for rooftop runoff that overflows to a drywell. In general, the primary function of cisterns is to capture and store rooftop runoff that can be used at a later time. The drywell is intended to accept overflow from the cistern in larger rain events, or when the cistern is already full from a previous storm event. Both the cistern and the drywell help to reduce peak flows leaving the site.

In addition, a rain garden is used here to treat runoff from the yard and paved areas, although rain gardens can also be designed to capture rooftop runoff. Permeable pavers can be used in the driveway and walkway areas, and a dry swale can be used along the road to collect the overflow from the rain garden, driveway, and walkways, and can help meet water quality requirements for the site.

1.9 The Value of Implementing LID

This introductory chapter highlights the environmental benefits of the LID approach. However, as discussed briefly in Section 1.4, there are also significant cost benefits to developers and communities when they follow the LID guidelines in this book. These benefits are seen in four areas:

- The initial construction cost for a project;
- Operation and maintenance costs for some LID-based best management practices
- Increased property values for LID sites, and;
- Future costs for clean-up or remediation of damaged watersheds or water bodies.

Cost savings are provided by using both better site design techniques and LID-based best management practices. A case study at the end of Chapter 2 highlights the cost savings provided by an LID project in Virginia. A 48% savings was provided by using a clustered site design and substituting open channel stormwater management systems for underground, fixed drainage systems.

Cost savings are found both in residential and commercial designs (Center for Watershed Protection, 1998). Four case studies developed by the Center for Watershed Protection showed savings of 5-20% when LID approaches were compared to standard designs for the same sites (Table 1.2).

Table 1.2 Comparison of Conventional Versus LID Construction Costs

	Med. Density Residential	Low Density Residential	Shopping Center	Office Park
Conv. Design	$1,539,000	$143,000	$782,000	$948,000
LID Design	$1,239,000	$126,000	$746,000	$788,000
Cost Savings	$300,000	$17,000	$36,000	$160,000
Percent Savings	**20%**	**12%**	**5%**	**17%**

The greatest cost savings were realized for the medium density residential development where there are the greatest opportunities for clustering the homes and therefore reducing infrastructure costs. It is safe to assume that similar savings can be achieved for projects in Hawaii, although the relative costs will be different given the locations of the case study sites and the time since the analysis was conducted.

Operation and maintenance costs for the BMPs described in Chapter 3 are similar, and sometimes less than those for standard drainage systems. In commercial settings, where parking lot islands are used for stormwater management, the overall site maintenance costs are likely to be less for an LID-based project. The landscaped islands must be maintained whether or not they are used for stormwater management. The extent of landscape maintenance is not too different for each approach, and if the islands are used for stormwater controls, there is no need to maintain other stormwater structures on the site as well.

Evidence has also shown that the values of properties built with an LID approach equal or exceed those developed based on a conventional design. Clustered homes adjacent to protected open space increased in value faster than homes in a standard subdivision in Amherst, Massachusetts (Lacy, 1991). Research in Illinois, Maryland and Virginia has found that home prices in dense residential areas are higher for homes adjacent to stormwater BMPs such as wet ponds or other aesthetic surface water features (Adams et al, 1986, Emmerling-DiNovo, 1995).

Finally, and perhaps most importantly, the use of an LID approach provides significant environmental benefits that can translate directly to cost savings in the need for future remediation of environmental resources. LID approaches can reduce the loading of sediments nutrients and pathogens to coastal waters and associated coral reefs in Hawaii. This improves the health of these systems and makes them more attractive for those interested in boating, snorkeling or diving. Future development using standard approaches will continue to threaten these systems, ultimately requiring expensive and difficult fixes if the heath of the coastal ecosystem is to be restored. If Hawaii hopes to preserve these resources for residents and visitors, the use LID techniques provides one cost effective tool to accomplish this goal.

1.10 References

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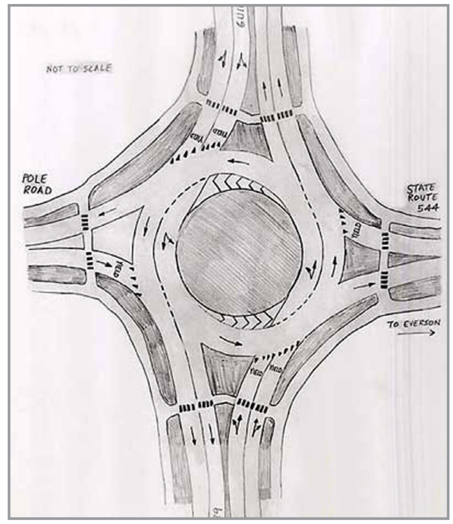
www.epa.gov/ebtpages/envismartgrowth.html Environmental Protection Agency (EPA) site on smart growth including a focus on community based approaches to reducing sprawl.

2 Road Design Criteria

2.1 Goal – Better Roadway Design Criteria



Roadways developed under the principals of Low Impact Design (LID) should satisfy standard design criteria, including safety, access and constructability, while maximizing the livability of pedestrians, neighborhoods and communities, and minimizing negative impacts from stormwater runoff and pollution.

The primary goals of conventional road design are efficiency and safety. Both are vitally important, but there is a growing consensus that other factors have been left out. These include the effects of roads on human and environmental concerns, and are especially significant at the local level. Recent publications from organizations such as the Institute of Transportation Engineers (ITE), the American Association of State and Highway Transportation Officials (AASHTO), and others are attempting to set better standards for local road design.

This chapter gives an overview of the evolution of conventional road design and its problems. Better roadway design criteria are developed based on recommendations by AASHTO, ITE and others; new ideas are presented where applicable, and comparisons are made to typical design standards for Hawaii where possible. Finally, a case study is presented illustrating a development that has successfully implemented some of these criteria.

2.2 Functional Classes of Roads

Road systems are typically grouped into three functional classes, arterial, collector and local.

Arterial roads, such as interstate highways, convey traffic on a regional scale and are grade-separated from all other roads, with access points spaced at regular intervals. These roads make up about 12 percent of the total mileage in the United States (AASHTO, 2004). Most of these roads are part of the National Highway System, and the standards for their design are set by the Federal Highway Administration (FHA). These standards are based on guidelines for the geometric design of highways developed by AASHTO and others, beginning in the early part of the 20^{th} Century.

Collector roads convey traffic on an intra-county or municipal scale and provide access to the arterial roads. In urban areas, major collector roads may receive in excess of 3,500 average daily trips (ADT), while minor collector roads typically receive 1,500 to 3,500 ADT (ITE, 1997). These roads make up about 23 percent of the total roadway mileage in the United States. Most of these roads are part of the state highway system; design standards for these roads are set by the state departments of transportation.

Local roads convey traffic on the residential level and provide access to collector roads, receiving an average of 100 to 1,500 ADT. These roads make up about 70 percent of the total roadway mileage in the United States. Design standards for these roads are set at the local or municipal level. Often, these standards were based on the same guidelines used to build state or federal highways, or on early attempts to design roads for the large scale subdivisions that were built starting in the 1950s. Although these standards can be appropriate for some uses, many of the roads that have been built based on them are over-designed. The remainder of this chapter will focus on local road design.

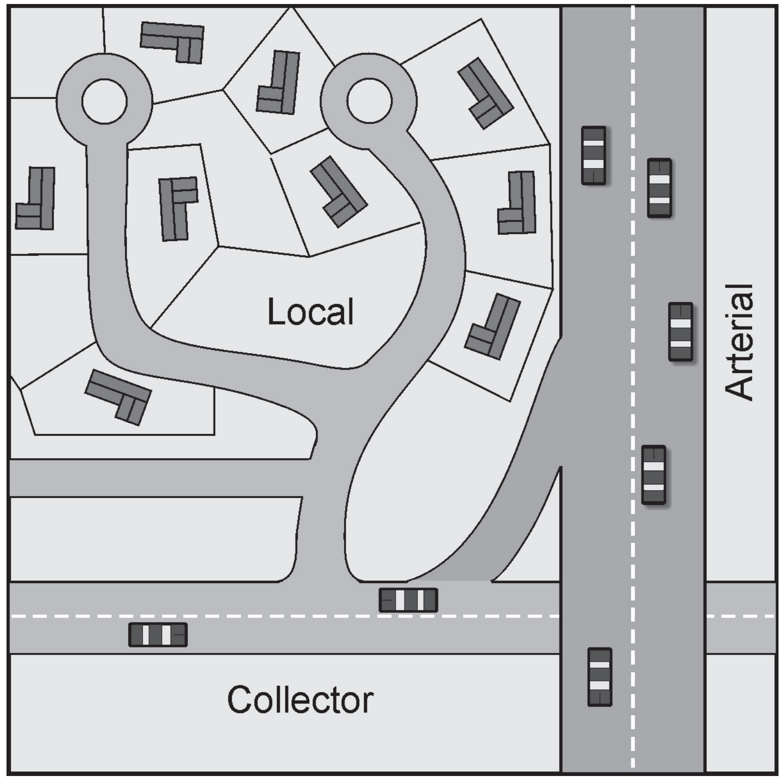


Figure 2.1 Typical road functional classes.

2.3 Conventional Road Design

Conventional design of local roads has typically focused on the efficient movement of vehicles and vehicular safety, to the detriment of other functions such as pedestrian activities, environmental concerns, cost and community aesthetics.

For example, a local urban road in Maui County must be 28 feet wide. This road provides one 8-foot parking lane and two 10-foot travel lanes. It is an appropriate design choice for larger streets with high traffic flows, and where ample on-street parking is required. This road can easily serve dense developments of 6.0 or more units per acre.

In areas of low density, 2.0 units or less per acre, or even medium density, 2.1 to 6.0 units per acre, this road may be too large. These areas do not require as much on-street parking as the denser development. Even in the dense areas, a 28-foot road is too large in some cases. Shorter roads, such as lanes or courts, which serve only a few houses and receive less than 250 ADT can be designed to be narrower based on the low traffic flows and vehicle speeds.

The long, wide stretches of pavement built as a result of an over-designed road create a number of problems:

- Vehicle speeds increase, posing a safety risk to both drivers and pedestrians. This has a negative effect on community character, and makes it difficult for law enforcement officers to perform proper policing.

- Capital expenditures for construction and maintenance are unnecessarily high.
- Larger right-of-ways (ROW) required increase clearing and reduce the amount of land available for residential and agricultural use.
- Larger impervious areas increase stormwater runoff and reduce groundwater infiltration. Pollutant loads are also larger, especially where curb-and-gutter systems are built.

2.4 Better Design Criteria

There is a growing consensus that better design criteria need to be developed for local roads. In 1974, the American Society of Civil Engineers (ASCE), Urban Land Institute (ULI) and National Homebuilders Association (NHBA) published *Residential Streets*, an early attempt to develop local road designs that were not based on highway standards. A subsequent edition published in 1993, and others such as *Guidelines for Residential Street Design* (ITE, 1997) and *Guidelines for Design of Very Low-Volume Local Roads* (AASHTO, 2001) further develop the design of roads tailored to the local setting.

Building shorter, narrower roads can have a number of benefits:

- Encourages moderate speeds through residential neighborhoods;
- Saves capital and resources;
- Creates neighborhoods that are more pedestrian friendly;
- Preserves valuable open space and agricultural land, and;
- Minimizes impervious area and its negative stormwater impacts.

The authority, and responsibility, for creating and implementing better design standards for local roads is at the town, municipal and county level. The guidelines developed by AASHTO, ITE and others are good starting points, but are designed to be recommendations rather than rules. The following elements of design criteria for roads are considered in this chapter:

- Right of Way (ROW) width
- Pavement width
- Parking requirements
- Driveway width and layout
- Curb requirements
- Size of vegetated buffer strips
- Sidewalk and bike path layout
- Stormwater treatment
- Design speed
- Minimum sight distance
- Maximum and minimum grade
- Minimum centerline radius
- Length and radius of cul-de-sacs
- Intersection approach speed and sight-distance
- Minimum intersection curb radii
- Intersection layout

Other design criteria, such as vertical curve sizes, street lighting, and intersection alignments are not discussed in this text but are given consideration in ITE's *Guidelines for Residential Subdivision Street Design*.

2.4.1 Right of Way (ROW) Width

The ROW must be wide enough to enclose all of the cross-sectional features of the roadway, including the pavement width, curbing, buffers, sidewalks, stormwater treatment and grading. Maui County recommends a 44-foot ROW width for 28-foot wide minor urban streets, and a 40-foot ROW for 22-foot wide minor rural streets. ITE guidelines are more conservative, recommending a minimum ROW width of 50 feet for low-density development and 60 feet for medium and high-density developments. 60 feet is a common design choice throughout the country, but can be excessive in many situations.

Wide ROWs reduce the amount of land that may be developed and increase the amount of clearing and grading that must occur, creating negative environmental and economic effects. The ROW need only be wide enough to contain all of the cross-sectional elements. The Maui County guidelines are a good choice given the size of the road; further reductions might be possible if the road width was decreased. For an 18-foot paved lane with 5-foot sidewalks offset six feet from the road and one foot from the edge of the property lines, the ROW may be as narrow as 42 feet. Similar reductions can be made for higher-order streets. ROW widths of 24 to 52 feet are practical for most applications.

A common justification for 60-foot ROW widths is that the additional space is required for future roadway expansion. However, the traffic volume of most residential streets is constant over time since additional units are unlikely to be constructed.

2.4.2 Pavement Width

The road should be wide enough to accommodate travel lanes, street parking (if required), and the passage of emergency vehicles and the occasional delivery truck. Maui County guidelines specify that minor urban roads be 28 feet wide and minor rural roads be 22 feet wide. These guidelines are appropriate for high-density development or high vehicle volumes, but may be excessive for smaller uses. AASHTO recommends that a two-lane rural road traveled at 25 mph should be 18 feet wide, while an urban road should be 20 to 28 feet wide for low-density developments and 28 to 34 feet wide for medium density developments, depending on street parking requirements (AASHTO, 2001; ITE, 1997). See Table 2.1 for a summary of typical pavement width requirements.

Minimizing the pavement width has several advantages. First, the developer will save money on labor and materials. Second, the ROW width (and clearing) will be reduced, and stormwater impacts will be minimized. Finally, narrower roads reduce vehicle speeds, enhancing safety and increasing the quality of life for nearby residences.

One way to reduce the width is to use a queuing lane (see Figure 2.3). Where traffic flow is low, two-way traffic can use a single lane, and passing vehicles can queue in the parking lane as necessary. AASHTO recommends that a single travel lane be 9 to 12 feet wide, and that parking lanes be 8 to 12 feet wide (AASHTO, 2004). Parking widths of 6 to 7 feet may be appropriate at low speeds. AASHTO recommends that the use of a queuing lane be limited to those streets receiving 50 or less ADT (AASHTO, 2001). However, queuing lanes can be effective for most local streets and even the smallest collector streets, (often termed 'sub-collector' streets), provided that traffic flows do not require the establishment of two clear lanes of travel. *Residential Streets* recommends that streets smaller than major collector streets, which have two lanes for both parking and travel and are usually 36 feet wide, can be 26 feet wide or less using a queuing lane (ASCE, 1990).

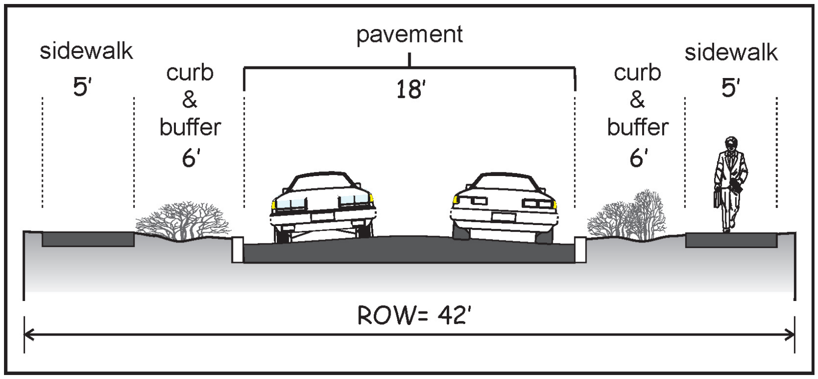


Figure 2.2 Typical cross-section and right-of-way.

Another option is to reduce or eliminate the need for on-street parking (for more on this topic, see the next section).

Sufficient width must be provided for the use of emergency vehicles. The most cited vehicle is a ladder truck used for fighting fires. This vehicle can navigate the typical 9- to 10-foot lane outlined above, but needs extra space for setting up its outriggers when raising the ladder. The National Fire Protection Administration recommends that a 20-foot unobstructed way be provided; some states such as Massachusetts and Virginia require an 18-foot width. Where street parking does not occur and the shoulder is constructed of a firm, stable material, the ladder truck can set up one of its supports on the shoulder.

Roads can be designed that minimize impervious area while taking the requirements of emergency vehicles into account.

Table 2.1

Minimum Pavement Widths (ft)						
	AASHTO *<= 400 ADT*	ITE	ULI/ASCE	Boulder, CO	Maui County	Recommended *Minimum*
Rural Minor *25 mph*	18	20	20	20	22	18
Rural Major/Collector *45 mph*	20	24	-	-	24	24
Urban Minor *Parking dependent*	20-28	20-28	22-26	20-26	28	20-28
Urban Major/Collector	28-34	24-36	36	-	36	24-36
Urban cul-de-sac	20-28	-	-	20	28	20
Minor agricultural	18	-	-	-	20	18

Design Vehicle Dimensions (AASHTO)

Passenger Car	7 feet wide, 19 feet long
Single Unit Truck	8.6 feet wide, 30 feet long

2.4.3 Parking Requirements

Parking requirements make up a significant portion of the impervious area in a development. Provision of street parking increases the roadway width, while off-street parking in the form of driveways and garages increases the total amount of impervious area per lot.

Off-street parking in residential districts is usually sized to accommodate the needs of the resident, while on-street parking is used for overflow requirements from visitors and other vehicles. ITE recommends that 1.5 to 3.0 spaces be provided per dwelling unit, depending on the size and type (ITE, 1997). Most communities require that 2 to 2.5 spaces be provided per single family home (CWP, 1998). Usually, a two-car garage and/or driveway is sufficient for these needs.

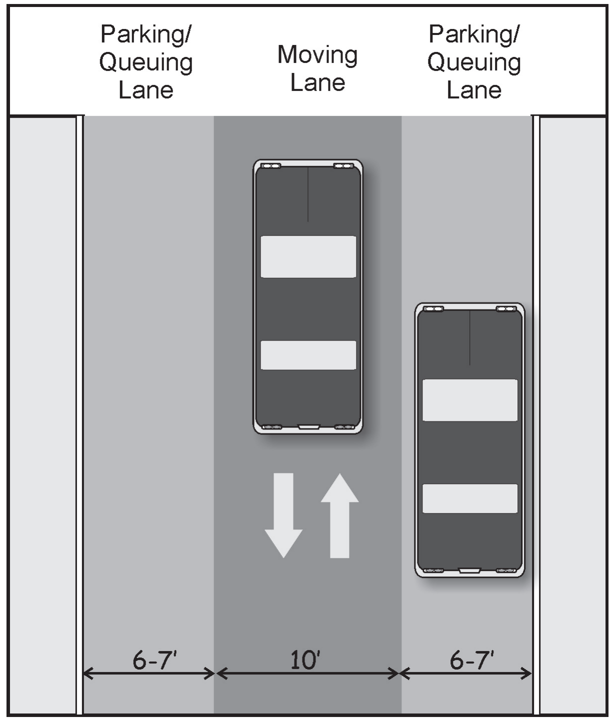


Figure 2.3 Example of queuing lane.

A typical on-street parking space is 20 feet long by 7 feet wide (CWP, 1998). Often, a continuous parking lane is provided on one or both sides of the street, depending on the density of the development. In rural or low-density developments, on-street parking may be accommodated on the grassy shoulder, provided that it has been sufficiently compacted and stabilized. The road may also be narrowed and widened to encourage parking in some areas and minimize impervious cover in others. Occasionally, lot configurations create driveways that are long enough to accommodate all reasonable overflow requirements, and no on-street parking is required.

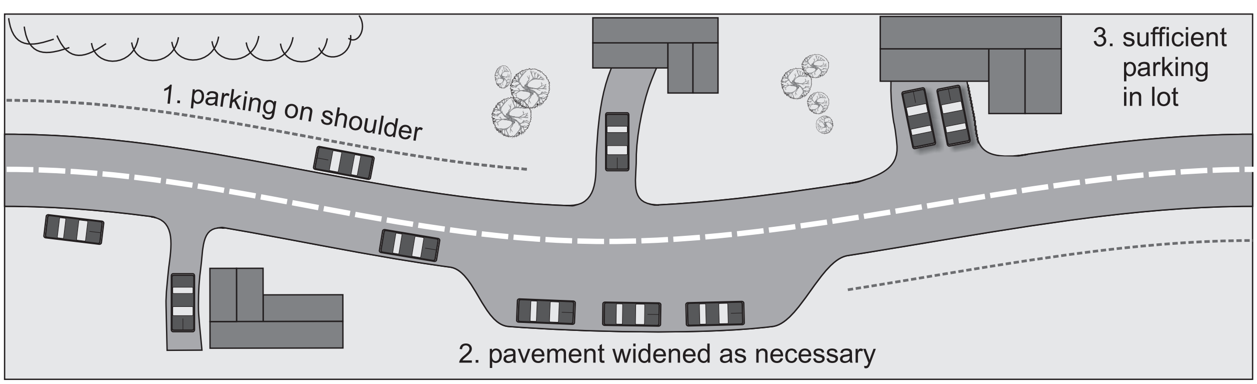


Figure 2.4 Alternative to street parking.

2.4.4 Driveway Width and Layout

Driveways must be wide enough to allow for the passage of vehicles, and long enough to satisfy parking requirements. Typically, a 10-foot wide drive is sufficient for one vehicle, while 20-foot wide drives are used for two car garages connected directly to the street (ITE, 1997). Driveways should always be designed with proper slopes, sight distances and radii.

One way to reduce the total amount of impervious area required by driveways in a development is to use shared driveways. These are privately owned and maintained roads, typically 16 feet wide. Maui County recommends that these roads serve no more than three residences, but two to six residences can be comfortably accessed. Careful design can provide sufficient space for overflow parking while reducing the overall area required. Since municipal authorities do not have oversight, it is important that the developer or a homeowners' association provide for the continued maintenance.

2.4.5 Curb Requirements

Curbs establish a clear boundary between the edge of the road and the buffer area, guarding against erosion and protecting the roadway edge. Curbing also protects pedestrians, and is an integral part of a closed drainage system, helping to deliver storm runoff to collection basins. Vertical curbing is most commonly used in urban areas, and is recommended by ITE for all medium to high-density developments (ITE, 1997). Rolled curbing, or asphalt berm, is less expensive and is typically used in medium to low-density developments. While vertical curbing provides greater protection for pedestrians, rolled curbing allows for on-street parking using part of the shoulder, and facilitates driveway construction.

One disadvantage to curbing is its cost; it is much more expensive to build a road with curbs and a closed drainage systems than with grassy shoulders and open swales. Curbs also prevent stormwater runoff from infiltrating along the side of the road, and create concentrations of debris, pollutants and bacteria. As a result, more runoff occurs at higher pollutant concentrations on curbed streets. Where practical, curbing should be eliminated and open drainage swales should be used in lieu of closed drainage systems, as outlined in brief in Section 2.5.8 and in detail in Chapter 3. In *Rural By Design*, Randal Arendt recommends that curb and gutter systems only be used where high densities prohibit the use of swales (four or more units per acre), or where erosion is a concern due to steep slopes of eight percent or more (Arendt, 1994).

One common argument against eliminating curbs is that it may increase the potential for surface erosion or failure of the road surface at the pavement edge. However, these effects can be mitigated by hardening the pavement grass interface through the use of grass pavers, or a low-rising concrete strip (CWP, 1998). The use of such a strip also increases the visibility of the roadway edge, enhancing traffic safety at night.

2.4.6 Size of Vegetated Buffer Strips

Vegetated buffer strips between the roadway edge and sidewalks or stormwater treatment facilities offer a number of advantages. Pedestrians are given increased protection, and space is available for such curb-side activities as garbage pickup. These areas also offer space for landscaping improvements, which offer aesthetic advantages and reduce vehicular speeds by as much as 10-15 mph (Burden, 1999).

ITE recommends that buffers 5 to 6 feet wide be constructed on both sides of the street; this is also a common requirement of many municipalities. In *Residential Streets*, a three to five-foot width is recommended. Using a narrower buffer strip reduces its effectiveness, but affords a narrower ROW width and reduces clearing and grading requirements.

2.4.7 Sidewalk and Bike Path Layout

Sidewalks can enhance community character by providing a safe place for people to walk and play. However, sidewalks are costly and increase the total impervious area of a development. Many communities require a 5-foot sidewalk on each side of the street; ITE recommends 4-6 foot sidewalks offset 1 foot from the edge of the ROW on both sides of the street, for medium- and high-density developments (ITE, 1997). Typically, the width requirement for a sidewalk is increased if it is constructed adjacent to the edge of the roadway, buildings, or shrubs (Burden, 1999).

Constructing 5-foot sidewalks on both sides of the street is not always appropriate, even in medium- to high-density developments. In *Better Site Design*, a 3-4 foot sidewalk on one side of the street is proposed for most situations. A reduction in property values and safety are two often-cited arguments against reducing sidewalk requirements. However, CWP found no marked reduction in either.

Where practical, sidewalks should be graded to drain into front lawns, reducing the total amount of runoff generated by the roadway. Where practical, walkways may be removed from the roadway entirely and used to provide access to natural features; see the case studies for more information. At low design speeds, (10 to 15 mph), sidewalks may be integrated with the road surface (Burden, 1999).

Bike paths are a nice amenity but also increase cost and imperviousness. Traffic volumes are low enough on most streets and lanes so as not to require them (Burden, 1999). Bicycle paths are recommended for larger routes where bicycle trips are more common and vehicle speeds are higher.

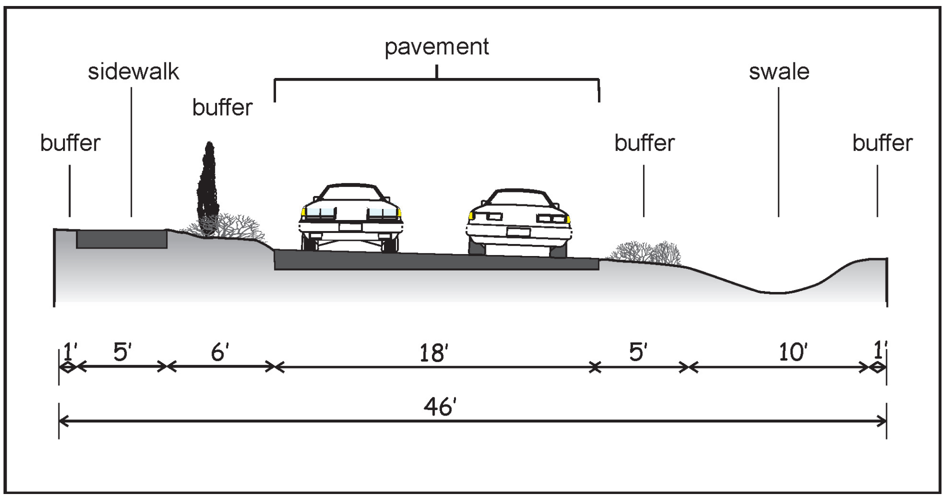


Figure 2.5 Example cross-section with open channel.

2.4.8 Stormwater Treatment

Open drainage systems enhance stormwater treatment and reduce runoff, and are encouraged where permitted by soils, slopes and lot configurations. Common treatment systems include dry swales, grass channels and biofilters. These are typically 1 to 2 feet deep and 7 to 10 feet wide. See Chapter 3 for more information on these and other stormwater management practices.

2.4.9 Design Speed

Many residential developments have a speed limit of 25 mph; designs for roads in Maui County are based on this speed. In general, many subdivision designs permit drivers to go faster, especially where roads are wide and straight. The Uniform Vehicle Code recommends that a design speed of 30 mph be used for residential developments; ITE recommends 20 to 30 mph, depending on the grade of the terrain.

Slower vehicle speeds increase public safety, giving drivers more time to react and reducing the severity of accidents. A design speed of 20 mph should be suitable for most residential developments (Burden, 1999), and can be encouraged by building narrow, windy roads. Developments that use geometry to reduce vehicle speeds are also easier for law enforcement officers to manage.

2.4.10 Minimum Sight Distance

The minimum sight distance at horizontal and vertical curves should be sufficient to allow drivers to come to a stop at the design speed. At 25 mph, AASHTO recommends 115 feet for low-volume and 125 feet for high-volume roads. ITE recommends 125 to 200 feet for residential streets, depending on the grade of the terrain and the design speed.

2.4.11 Maximum and Minimum Grade

To allow for proper drainage, the general standard for the absolute minimum lateral and longitudinal slopes for roads is 0.5%, and the recommended minimum is 1.0%. Maui County allows roads to slope at a minimum of 0.25%. In hilly terrain, the road grade should be a compromise between safety and economics; steeper roads may be cheaper to build but can pose a safety risk. ITE recommends that the maximum grade for roads in hilly terrain be 15%.

2.4.12 Minimum Centerline Radius

The minimum centerline radius of a road is a function of its design speed and traffic volume, and of the friction factor of the pavement surface. At 25 mph, AASHTO recommends centerline radii of 90 to125 feet for ADT less than 250 and 135 to 205 feet for ADT between 250 and 400. ITE recommends 100 to 200 feet, depending on the grading and design speed of the road.

Larger turn radii can lead to increased vehicle speeds. Radii of 90 to 120 feet can help maintain vehicle speeds at 20 mph (Burden, 1999).

2.4.13 Length and Radius of Cul-de-sacs

Lanes and ways terminating in a cul-de-sac offer lower vehicle flows and speeds, increasing quality of life and often creating higher property values. However, such dead end streets offer reduced access in the time of an emergency and can increase the total impervious area of a development. Building narrow streets with sharper turns is a preferable alternative to cul-de-sacs, since it can accomplish the same goal of reducing traffic disturbances, while maintaining essential connectivity between neighborhoods.

Where cul-de-sacs must be built, they are generally designed for a maximum of 200 ADT. This is equal to the traffic generated by 20 to 25 houses at 8 to 10 trips per day. Depending on the density of the development, ITE recommends maximum cul-de-sac lengths between 700 and

1,500 feet. Cul-de-sacs in Maui County may be no longer than 800 feet in agricultural areas and 550 feet in other areas. Recommending that cul-de-sacs be as short as possible is a good practice as it may help to reduce their overall use.

A cul-de-sac must be wide enough to accommodate the turning radii of large emergency vehicles such as fire trucks. Maui recommends a minimum radius of 43 feet and a minimum pavement width for the access road of 28 feet for urban areas and 22 feet for rural areas (these roads may be too wide in some cases, as illustrated above). The impervious area can be minimized by creating a vegetated area in the center, provided that a sufficient paved width is maintained, (ITE recommends a minimum of 25 feet). Newer fire trucks have reduced turning radii, and the paved radius may be reduced to 30 to 40 feet in some cases (ASCE, 1990). See Table 2.2 for a summary of turning radii for AAHSTO design vehicles. Where a vegetated area is used, a 20-foot paved width may be sufficient for these vehicles (CWP, 1998).

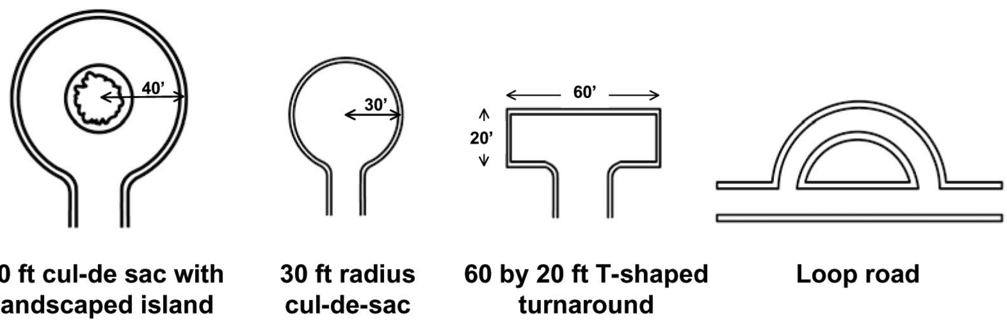


Figure 2.6 Common and alternate turnarounds.

Alternative layouts, such as a tee- or hammer-shaped turnaround, may be appropriate for streets shorter than 200 feet in length. These areas offer significant reductions in impervious area over the standard cul-de-sac. A loop road is also a good option; these provide multiple access points for emergency vehicles and can carry double the traffic volume of a cul-de-sac. Loop roads also favor the construction of tee-style intersections, which offer numerous benefits (see Section 2.5.16, below).

2.4.14 Intersection Approach Speed and Sight-distance

An intersection approach speed of 20 to 25 mph should allow the motorist to come to a comfortable stop within 100 feet (ITE, 1997). At increased speeds, greater site distances are required to allow drivers to recognize approaching obstacles. An appropriate sight distance triangle must be maintained through building setbacks and reduction in landscaping. AASHTO's publications offer a good treatment of this topic.

Table 2.2

Turning Radius for Design Vehicles (AASHTO)	
Passenger Car	24 ft outside, 14 ft inside
Single Unit Truck	42 ft outside, 14 ft inside

2.4.15 Minimum intersection curb radii

Larger intersection curb radii minimize lane encroachments by turning vehicles, but lead to an increase in costs, impervious cover, and vehicle speeds. Wide intersections also create an environment that is less friendly to the pedestrian. Curb radii should be set to the minimum size required by turning vehicles and lane configurations. AASHTO recommendations range from 15 feet for smaller roads to 25 feet for collector streets.

2.4.16 Intersection Layout

Tee-style intersections offer a number of advantages over crosses, and should be used where practical. Tee intersections tend to be safer (ITE, 1997), provide attractive terminating vistas, decrease vehicle speeds, and reduce points of pedestrian-vehicle conflict (Burden, 1999). In order to minimize conflict between adjacent intersections, tees should be spaced a minimum of 125 feet apart (ITE, 1997). Currently, Maui County recommends that intersections be spaced no closer than 150 feet.

A sub-collector road with a number of loop roads terminating in tee-style intersections offers a good opportunity to minimize impervious cover, enhance pedestrian safety and reduce vehicle speeds, while increasing the overall flow of traffic.

Figure 2.7 Sample layout.

2.5 Summary

Design criteria are summarized below in Table 2.3:

Summary						
Design Criteria		Units	Guidelines			
			AASHTO	ITE	Maui	Reccomended
ROW	Width	ft	-	50 (low density) 60 medium density	40 (rural) 44 urban	varies
Pavement Width	Single lane	ft	10-12	-	10	9
	Parking lane	ft	8-12	-	8	7
	Minor rural road	ft	18	-	22	18
	Minor urban road	ft	20 - 28	20 - 28	28	20 - 28
Parking	Spaces per lot	#	-	1.5-3	-	1.5-3
	Provide urban street parking	yes/no	-	varies	yes	varies
Driveways	Width, max lots for shared drive	ft,#	16, 6	-	16, 3	16, 6
Curb	Required at density	units/ac	-	2	-	4
Buffer strip	width	ft	-	5-6	-	3-6
Sidewalks	Reuired on both sides	yes/no	-	yes	-	varies
	Minimum width	ft	-	5	-	3-5
Design speed	Residential area	mph	25	25-30	25	20-30
Sight distance	Minimum	ft	115-125	125-200	-	115
Grade	Minimum slope	%	-	0.5%	0.25%	0.5%
Centerline	Minimum radius	ft	90-125	100-200	-	90-125
Cul-de-sac	Maximum traffic flow	ADT	200	200	200	200
	Max length	ft	-	700-1500	550-800	550-800
	Minimum radius	ft	-	45	43	40
Curb radius	Minimum	ft	15-25	-	-	15-25
Intersections	Minimum offset	ft	-	125	150	125

2.6 Case Study

The Fields at Cold Harbor, Hanover County, Virginia

The Fields at Cold Harbor is a 19 unit residential development in Hanover County, Virginia. The heavily forested parcel is 120.3 acres in size, includes an existing farm and farmhouse, and historic military earthworks dating to the Civil War. It is zoned as a Rural Conservation District (RCD), which allows for the construction of low-density, single family homes, provided that at least 70% of the site was set aside as conservation area to preserve its rural character.

The development incorporates a number of LID principals, including many that were described in this chapter. A project based on standard design criteria was drafted during the design phase for comparison.

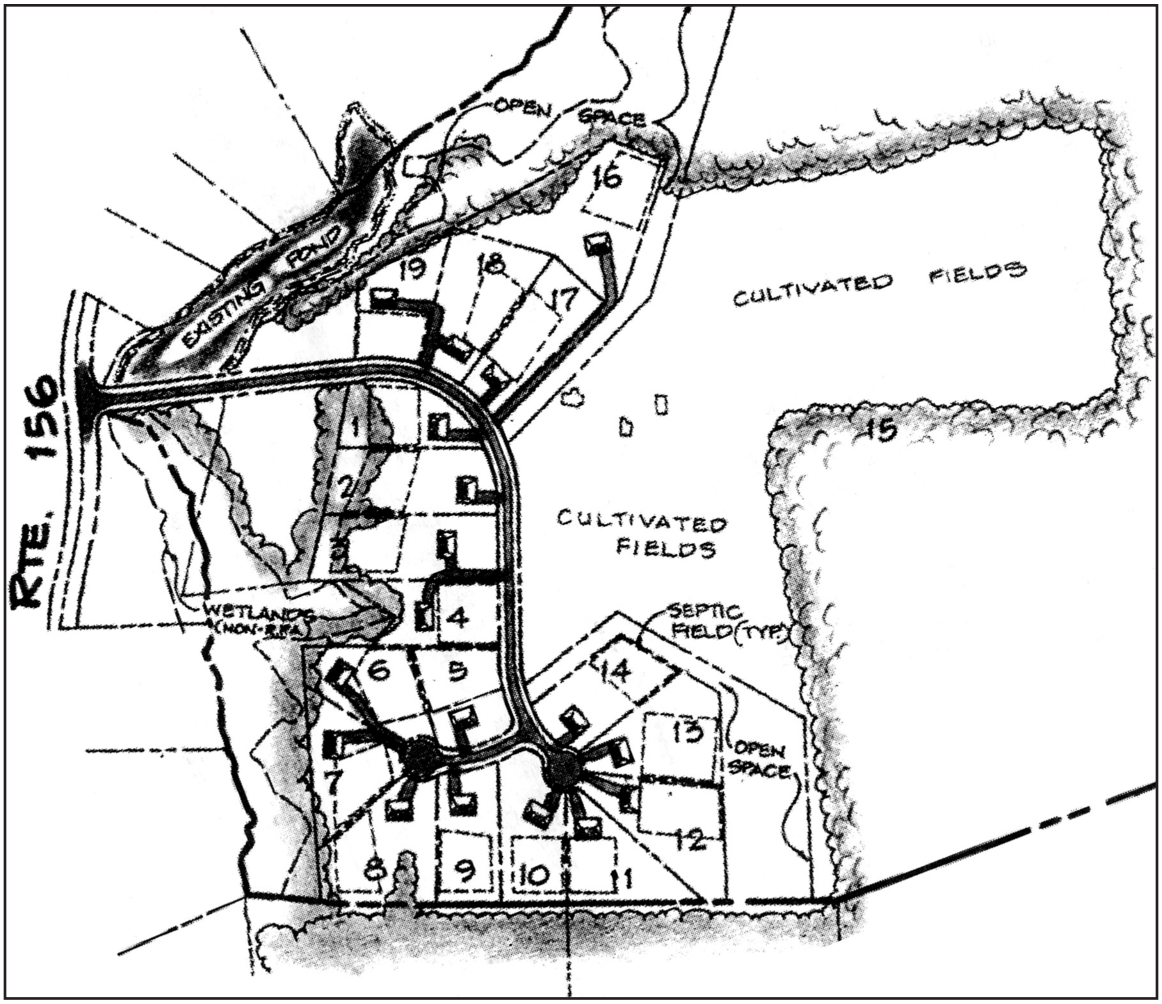


Figure 2.8 Plan view of the Fields.

Native plants and trees were conserved using an open space plan and a clustered development, allowing for 80% of the site to be preserved. Lot sizes were reduced from an average of 2.5 acres in the standard design to a minimum of 1.0 and a maximum of 1.4 acres. Shorter setbacks and frontages as a result of this design helped to reduce the total length of the roadway. In addition to these achievements, the project addressed the following road design criteria:

Pavement width:
An 18 foot, shoulder and ditch roadway was used. Standard road designs would have dictated a 28-foot, curb and gutter road. This choice greatly reduced the total impervious area in the site and offered dramatic savings in infrastructure.

Parking requirements:
At least two spaces were provided per lot. On street parking was not assumed, which allowed for a reduction in road width, above. Standard design criteria would have assumed that parking would occur on both sides of the streets. Eliminating the on-street parking was a better fit given the site's rural character.

Driveway width and layout:
Two pairs of lots used shared driveways, reducing the total impervious cover of the site. This would not have been done in the standard design.

Curb requirements:
Curbs were not used, allowing runoff from the road to sheet flow directly into a grass channel.

Sidewalk and bike path layout:
In the standard design, two 5-foot sidewalks were required. In the final design, these sidewalks were replaced with a walking trail that provided access to the preserved natural features of the site. This design choice helped to minimize the impervious cover of the site, while offering residents an opportunity to better enjoy its amenities.

Stormwater treatment:
Grass channels were used in lieu of the traditional curb and gutter systems. This provided better treatment than the standard design, reduced peak flows and lowered infrastructure costs.

The final design was a dramatic improvement to the standard design. In existing conditions, impervious cover was at 3.3%; this was raised to 7.4% in the final design, down from 8.3% in the standard design. The open channel design offered better treatment of stormwater and helped increase the total infiltration rate by 6.4%. Finally, infrastructure costs were nearly cut in half, totaling $278,000 in the final design and $527,000 in the standard design.

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3 Stormwater Management

3.1 Introduction - Why Stormwater Matters

Portions of the Hawaiian Islands receive a lot of rain, while some areas are very dry. The average annual rainfall exceeds 300 inches per year in many mountainous areas.

These climatic conditions combined with the region's unique volcanic and coral geologic formations, sensitive water resources and significant land development forces make stormwater a very significant environmental and economic issue.

Historically, stormwater has been viewed as strictly a drainage issue, a waste to be disposed, and has been routed to the nearest discharge location, infiltrated with little or no pre-treatment, or conveyed directly to receiving waters via large concrete channels.

Along with development comes an increased amount of impervious surfaces, precluding the natural infiltration of rainwater into the underlying groundwater system. As a result, the groundwater "lens" (which serves as the principle drinking water source) is depleted. Or, in the instances where stormwater is infiltrated without adequate pre-treatment, groundwater quality is degraded.

In this section, water quality and quantity issues related to stormwater are discussed. This section also describes sensitive environmental resources areas, such as drinking water supplies and wetlands.

Impact of Stormwater Runoff on Hawaiian Watersheds

Urban development has a profound influence on the quality of the waters of Hawaii. To start, development dramatically alters the local hydrologic cycle (see Figure 3.1). The hydrology of a site changes during the initial clearing and grading that occur during construction. Trees that had intercepted rainfall are removed, and natural depressions that had temporarily ponded water are graded to a uniform slope. The spongy humus layer of the native vegetation that had absorbed rainfall is scraped off, eroded or severely compacted. Having lost its natural storage capacity, a cleared and graded site can no longer prevent rainfall from being rapidly converted into stormwater runoff.

The situation worsens after construction. Rooftops, roads, parking lots, driveways and other impervious surfaces no longer allow rainfall to soak into the ground. Consequently, most rainfall is directly converted into stormwater runoff. This phenomenon is illustrated in Figure 3.2, which shows the increase in the volumetric runoff coefficient (R_v) as a function of site imperviousness. The runoff coefficient expresses the fraction of rainfall volume that is converted into stormwater runoff. As can be seen, the volume of stormwater runoff increases sharply with impervious cover. For example, a one-acre parking lot can produce 16 times more stormwater runoff each year than a one-acre meadow (Schueler, 1994).

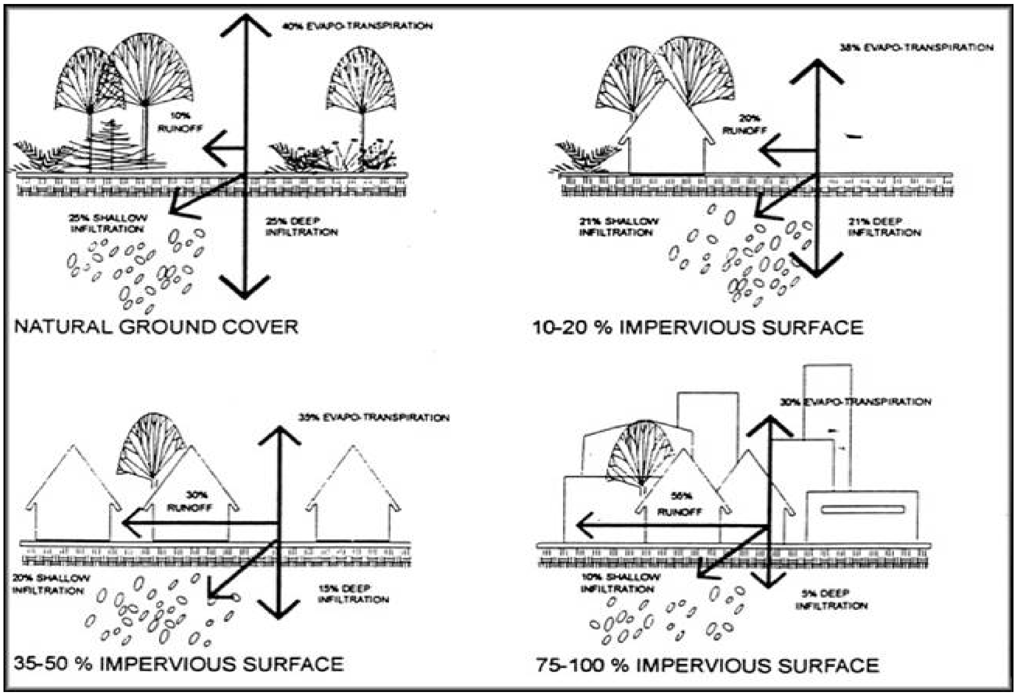


Figure 3.1 Water Balance at Developed and Undeveloped Sites (adapted from Prince George's County, 1999)

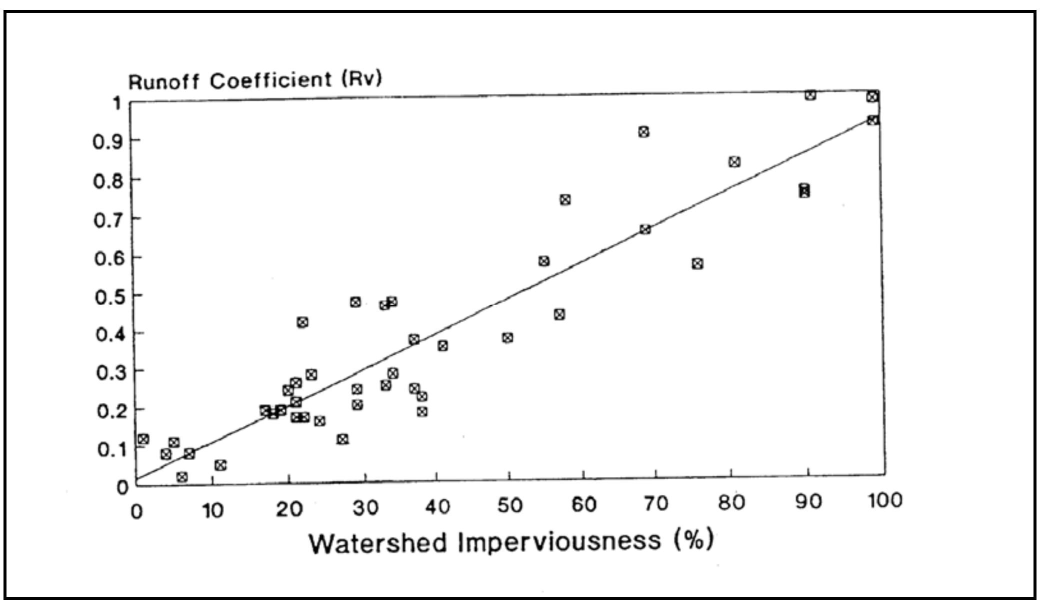


Figure 3.2 Relationship Between Impervious Cover and Runoff Coefficient (Schueler, 1987)

The increase in stormwater runoff can be too much for the natural drainage system to handle. As a result, the drainage system is often “improved” to rapidly collect runoff and quickly convey it away (using curb/gutters, enclosed storm sewers, and lined channels). The stormwater runoff is subsequently discharged to downstream waters, such as streams, wetlands, lagoons, or near-shore bays.

Impacts to Natural Stream Channels

As pervious rangelands and forests are converted into less pervious urban soils or pavement, both the frequency and magnitude of storm flows increase dramatically. As a result, the bankfull event occurs two to seven times more frequently after development occurs (Leopold, 1994). In addition, the discharge associated with the original bankfull storm event can increase by up to five times (Hollis, 1975).

Overbank floods are ranked in terms of their statistical return frequency. For example, a flood that has a 50% chance of occurring in any given year is termed a “two-year” flood. The two-year storm has been frequently designated as the “bankfull flood,” as researchers have demonstrated that most natural stream channels on the islands have just enough capacity to handle the two-year flood before spilling out into the floodplain. This rainfall depth is termed the two-year design storm. Similarly, a rain event that has a 10% chance of occurring in any given year is termed a “ten-year storm."

Urban development increases the peak discharge rate associated with a given design storm because impervious surfaces generate greater runoff volumes and drainage systems deliver it more rapidly to a stream. The change in post-development peak discharge rates that accompany development is profiled in Figure 3.3.

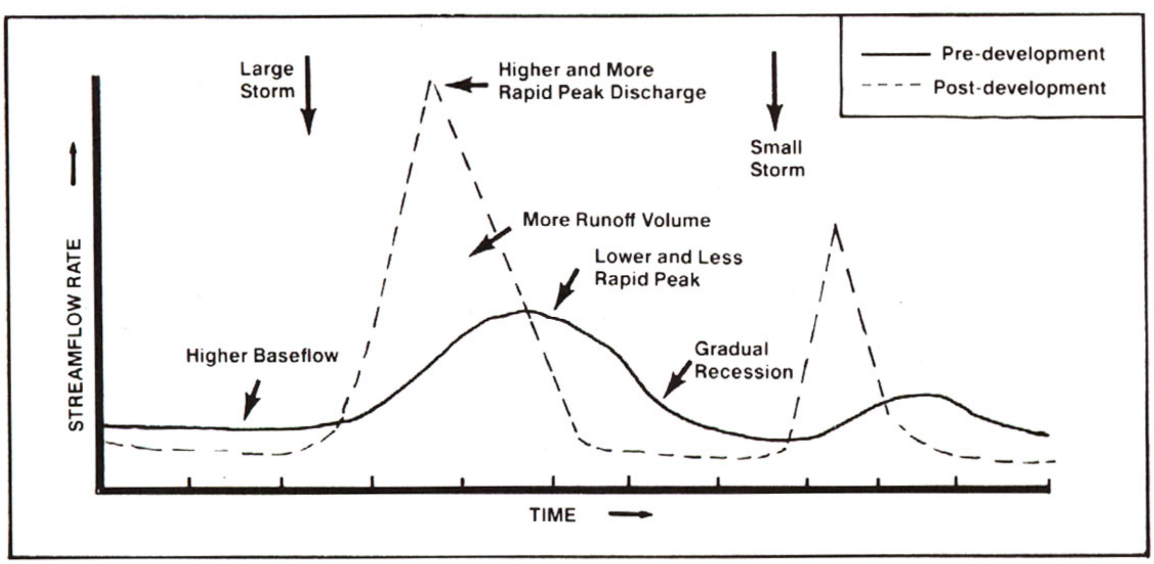


Figure 3.3 Hydrographs Before and After Development

Impacts to Water Quality

Impervious surfaces accumulate pollutants windblown in from adjacent areas, leaked from vehicles, or deposited from the atmosphere. During storm events, these pollutants are quickly washed off and rapidly delivered to downstream waters. Water quality impacts are numerous, and pollutants include sediments (total suspended solids or TSS), nutrients (nitrogen and phosphorus), and pathogens (bacteria and viruses).

Sediment (Suspended Solids)

Sources of sediment include particles that are deposited on impervious surfaces and subsequently washed off by a storm event, as well as the erosion of streambanks and construction sites. Streambank erosion is a particularly important source of sediment, and some studies suggest that streambank erosion accounts for up to 70% of the sediment load in urban watersheds (Trimble, 1997).

Both suspended and deposited sediments can have adverse effects on aquatic life in streams, ponds, and bays. Turbidity resulting from this sediment can reduce light penetration for submerged aquatic vegetation critical to estuary health. In addition, the reflected energy from light reflecting off suspended sediment can increase water temperatures (Kundell and Rasmussen, 1995). Sediment can physically alter habitat by destroying the riffle-pool structure in stream systems and smothering benthic organisms. In addition, sediment transports many other pollutants to our water resources.

Sedimentation is also the most significant threat to the coral reefs around Hawaii. High sediment loads can kill coral by (1) settling directly on top of corals and smothering them and (2) inhibiting photosynthesis by reducing the amount of light which gets through the water column, and (3) providing excess nutrients to the marine waters through particles that are carried with sediments.

Nutrients

Runoff from developed land has elevated concentrations of both phosphorus and nitrogen, which can enrich streams, reservoirs, and bays (known as eutrophication). Significant sources of nitrogen and phosphorus include fertilizer, atmospheric deposition, sewage (e.g., from overflows and faulty septic systems), animal waste (both domestic and feral), organic matter, and streambank erosion. Data from mainland US suggest that lawns are a significant contributor, with concentrations as much as four times higher than other land uses, such as streets, rooftops, or driveways (Steuer et al., 1997; Waschbusch et al., 2000; Bannerman et al., 1993). Nutrients are of particular concern to ponds, lakes, and estuaries and are a major source of degradation in some of the islands' waters.

Bacteria

Bacteria levels in stormwater runoff routinely exceed public health standards for water contact recreation. Some stormwater sources include pet waste and urban wildlife. Other sources in developed land include sanitary and combined sewer overflows, wastewater, and illicit connections to the storm drain system. Bacteria are a leading contaminant in many of the waters of Hawaii and have led to many beach closures in recent years.

Environmental Resource Areas and Sensitive Receptors

The Hawaiian Islands contain a broad range of environmental resource areas, which are sensitive to stormwater discharges. Critical resource areas include groundwater, streams, ponds, wetlands, beaches and coral reefs. They are impacted by both hydrologic and water quality aspects of stormwater runoff, as were discussed above. This section explains the sensitivity of the various resource areas and evaluates their potential response to alternate stormwater management strategies and practices.

Groundwater

Groundwater serves as the primary source of drinking water to Hawaiians. The only source of groundwater recharge is precipitation, which infiltrates to the subsurface and recharges the underlying water table (the upper surface of the groundwater system). A significant portion of this is lost to evapotranspiration, some is lost to surface runoff, and the remaining portion is available as "recharge" to groundwater.

As land development occurs, impervious surfaces preclude the natural infiltration of this rainwater, thereby reducing the recharge rate. This results in a lowering of the water table, and a reduction of the thickness of the groundwater lens. Ultimately, development can lead to a depletion of groundwater resources, increased salt water intrusion to drinking water wells, and increased concentrations of other pollutants derived from urban runoff.

Water withdrawals for drinking water and irrigation also deplete the groundwater lens and result in declining water table elevations and corresponding decreases in the thickness. The Ghyben-Herzberg principle suggests that for each foot that the water table declines, the lens thickness decreases by 40 feet (based upon the 1:40 density ratio between fresh and salt water). Therefore, small reductions in recharge and the water table can significantly affect the groundwater system.

One potential remedy for this "de-watering" impact is to collect stormwater runoff and to infiltrate it to help restore (or enhance) natural recharge rates. To some degree, this already occurs in current stormwater management implementation. It is possible to collect and infiltrate enough stormwater to match the natural (pre-development) recharge rates. This may be a viable option to mitigate and compensate for other sources of water consumption and groundwater de-watering, such as groundwater withdrawals for drinking water and irrigation purposes.

However, the infiltration of stormwater raises some important water quality issues. Stormwater is commonly degraded with a broad range of pollutants collected from the land surface or accompanying precipitation. Secondly, aquifers can be highly permeable and, therefore, very susceptible to contamination. Thus, depending on the land use, stormwater can require significant pre-treatment prior to infiltration to protect the quality of groundwater resources. This may be accomplished with certain stormwater BMPs that provide comprehensive treatment. Wellhead protection areas have been delineated showing the specific groundwater areas that contribute to the pumping water supply wells and require the highest level of protection to ensure a safe drinking water supply. Currently, recharge is not a requirement for development sites but can be an effective stormwater management tool if designed properly.

Freshwater Streams, Ponds and Wetlands

There are numerous streams (perennial and intermittent), ponds, and wetlands throughout Hawaii. They provide important aquatic habitat for a broad range of fish, amphibian, mammal and bird species, and as recreational resources for humans. In addition, surface water provides more than 50% of the irrigation water in Hawaii, and in some places, is the main source of drinking water. Streams are also a source of hydroelectric power and support certain traditional Hawaiian gathering customs and taro production (Oki, 2003).

Stream flow is derived from overland runoff and baseflow from groundwater, which discharges into streambeds. If baseflow is continuous throughout the year, the stream is perennial. If groundwater elevations fall below the natural stream bed elevation, the stream is intermittent. In either case, stream ecosystems are very dependent upon the maintenance of natural groundwater levels and corresponding groundwater discharges to the streams.

Each stream ecosystem is adapted to its natural flow regime, which is a mixture of surface runoff events and groundwater baseflow. Stormwater management practices associated with land development within watersheds can significantly alter the timing and rates of surface flow and groundwater discharge, thereby impacting stream ecosystems. In some cases, naturally occurring perennial streams may dry up seasonally in a developed watershed, significantly altering the habitat. Similarly, water quality impacts caused by increased nutrients and sedimentation can significantly impact streams ecosystems. Finally, streams, particularly small first- and second-order streams, are especially susceptible to increased channel erosion associated with altered hydrology and land development.

Ponds provide unique habitats and are also sensitive to stormwater discharges within their watersheds. Eutrophication is a common problem in fresh water ponds, and is the result of excessive phosphorus loading, which can cause excessive weed or algal growth and ultimately can cause depleted oxygen levels, fish kills, and noxious odors. Although both phosphorus and nitrogen contribute to excessive plant growth, phosphorus is the limiting nutrient of freshwater pond environments. Common sources of phosphorus include phosphate-containing cleaners or detergents, human and animal waste, and lawn fertilizers.

Wetlands provide a broad range of habitat and recreational values. They too are susceptible to impacts from stormwater in terms of both hydrology and water quality changes. Wetlands are defined and entirely dependent upon surface and near surface hydrologic conditions (water levels to within 12 inches of the surface of the ground), which support hydrophytes (wetland vegetation) and hydric soils. Similar to the other freshwater resource areas discussed above, wetlands are very sensitive to water level changes and to alterations in water inputs. Therefore, stormwater must be managed within the watersheds to wetlands in a manner that preserves natural flow regimes. Wetlands are also susceptible to pollutant loading increases, particularly phosphorus.

Coastal Waters

Coastal waters surround each of the Hawaiian Islands and serve as the ultimate "discharge area" for all surface runoff. They are valuable for the support and propagation of shellfish and other marine life, conservation of coral reefs, oceanographic research, and serve as a very significant recreational resource for humans. Coastal water quality issues include eutrophication, damage to coral reefs (including sedimentation), and bacterial/viral pollution of swimming beaches. Sediments cause physical damage including decreased water clarity and smothering of coral and other marine resources (Fukuda, 2004). Nutrients (typically nitrogen for coastal environments) cause eutrophication, which results in excessive algae and weed growth, depleted dissolved oxygen levels, and foul odors.

3.2 The Concept of Integrated Stormwater Management

Integrated stormwater management design involves the integration of site design practices and procedures with the design and layout of stormwater infrastructure to attain stormwater quality and quantity management goals.

The integrated stormwater management concept uses the following elements or steps:

1. Low-impact Development Practices and Techniques – Protect and utilize natural features of the site to reduce runoff and pollutants. For an overview of low-impact development, please refer to Chapter 1.

2. Design Criteria for Stormwater Control Requirements – Calculate the volume of runoff to be controlled for water quality, as described below in Section 3.3. Water quantity shall be designed to meet local County regulations.

3. Downstream Assessment – If necessary or desired, perform a downstream analysis to ensure that the proposed development is not adversely impacting downstream properties after the volumes calculated above have been controlled.

4. Selection and Sizing of Structural Stormwater Controls and Conveyance – Structural control measures are selected using a screening process, then sized, designed and positioned in a development plan. The reader can use the matrices found in Section 3.5 to identify the most appropriate BMP or group of practices to use at a site.

5. Preparation of Final Site Plan – The last step in the process is the preparation of a final site plan that meets all of the construction and stormwater criteria and preserves or even enhances the water quality and natural function of the site.

The aim of these steps is to provide a process that will address the comprehensive stormwater management goals presented in Section 3.3, while at the same time providing ease of application for the land developer and a streamlined process for the review of a project.

The integrated design process is illustrated in Figure 3.4.

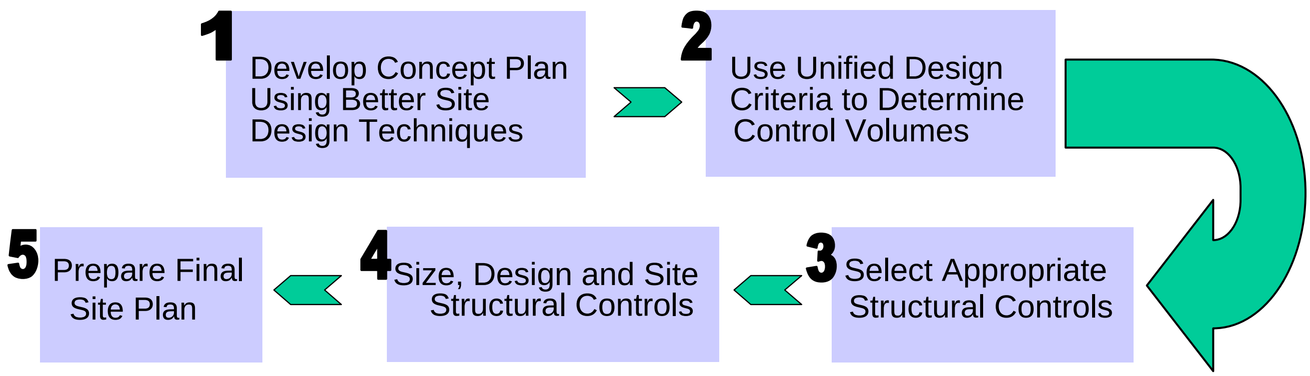


Figure 3.4 The Integrated Stormwater Management Site Design Process

The following principles should be kept in mind in using this process and preparing a stormwater management plan for a development site:

- Site design should utilize an integrated approach to deal with stormwater quantity, quality and protection of downstream properties and/or streambanks.

  The stormwater management infrastructure for a site should be designed to integrate drainage and water quantity control, water quality protection and downstream property and channel protection. Site design should be done in unison with the design and layout of stormwater infrastructure to attain stormwater management goals. Together, the combination of better site design practices and effective infrastructure layout and design can mitigate the worst stormwater impacts of most urban developments while preserving water quality and aesthetic attractiveness.

- Stormwater management practices should strive to utilize the natural drainage design principles and require as little maintenance as possible.

Almost all sites contain natural features that can be used to help manage and mitigate runoff from development. Features on a development site might include natural drainage patterns, depressions, permeable soils, wetlands, floodplains and undisturbed vegetated areas that can be used to reduce runoff, provide infiltration and stormwater filtering of pollutants and sediment, recycle nutrients, and maximize on-site storage of stormwater. Site design should seek to improve the effectiveness of natural systems rather than to ignore or replace them. Further, natural systems typically require low or no maintenance and will continue to function many years into the future.

- Structural stormwater controls should be implemented after site design and nonstructural options have been exhausted.

Operationally, economically, and aesthetically, conservation site design and the use of natural techniques offer significant benefits over structural stormwater controls. Therefore, all opportunities for utilizing these methods should be explored before implementing structural stormwater controls such as engineered wet ponds and sand filters.

- Structural stormwater solutions should attempt to be multi-purpose and be aesthetically integrated into a site's design.

A structural stormwater facility need not be an afterthought or ugly nuisance on a development site. A parking lot, soccer field or city plaza can serve as a temporary storage facility for stormwater. In addition, water features such as ponds and wetlands when correctly designed and integrated into a site can increase the aesthetic value of a development.

- "One size does not fit all" in terms of stormwater management solutions.

Although the basic problems of stormwater runoff and the need for its management remain the same, each site, project and watershed presents different challenges and opportunities. For instance, an infill development in a highly urbanized town center or downtown area will require a much different set of stormwater management solutions than a low-density residential subdivision in a largely undeveloped watershed. Therefore, local stormwater management needs to take into account differences between development sites, different types of development and land use, various watershed conditions and priorities, the nature of downstream lands and waters, and community desires and preferences.

3.3 Stormwater Criteria and Standards

Effective stormwater management needs to address both water quality and water quantity controls. This requires an integrated approach to applying an appropriate suite of practices to meet a range of design criteria. This guidance is oriented towards meeting water quality treatment goals. Consult local County regulations for appropriate quantity controls.

It is widely recognized that in order to meet various water quality standards and classifications, some level of stormwater runoff treatment is necessary. There is conclusive water quality and biological data that show the toxic effect of untreated nonpoint source pollution. Small-sized, frequently occurring storms account for the majority of rainfall events that generate urban stormwater runoff. These frequent storms also account for a significant portion of the annual pollutant loadings. Therefore, by capturing and treating these frequently occurring smaller rainfall events, it is possible to effectively mitigate the water quality impacts of stormwater runoff.

Larger storms also have impacts associated with them from channel degradation, surface erosion, gullying, and flood damage. These impacts can be significantly reduced by storing and releasing stormwater runoff in a gradual manner that ensures critical erosive velocities and peak discharges are not exceeded.

Hawaii has seen tremendous population growth and commercial development over the last several years. Controlling stormwater pollution from development sites is a priority with regards to stormwater controls and impacts to receiving water bodies. This section presents recommended general performance standards and treatment criteria for sizing BMPs to meet pollutant removal objectives at development sites in Hawaii. The focus of this section is water quality - water quantity criteria are not covered here and vary based on island and location.

3.3.1 Designation of Stormwater "Hotspot" Land Uses

There are specific conditions where stormwater management and treatment requires an added level of scrutiny. These conditions are referred to as stormwater "hotspots." Discussion of the special considerations warranted for these applications is provided below.

A stormwater hotspot is defined as a land use or activity that generates higher concentrations of hydrocarbons, trace metals or toxicants than are found in typical stormwater runoff, based on monitoring studies. If a site is designated as a hotspot, it has important implications for how stormwater is managed. First and foremost, stormwater runoff from hotspots cannot be allowed to infiltrate into groundwater without prior water quality treatment. Second, a greater level of stormwater treatment is needed at hotspot sites to prevent pollutant washoff after construction. This will involve preparing and implementing *a stormwater pollution prevention plan* (SWPPP) that involves a series of operational practices at the site that reduce the generation of pollutants from a site or prevent contact of rainfall with the pollutants. Visit the USEPA website to learn more about how to prepare a SWPPP (http://cfpub.epa.gov/npdes/stormwater/swppp.cfm). **Table 3.1** provides a list of designated hotspots for Hawaii. Applicants should prepare a SWPPP for review and approval by the local authority prior to construction.

Table 3.1 Classification of Stormwater Hotspot Land Uses

The following land uses and activities are considered *stormwater hotspots:* • vehicle salvage yards and recycling facilities • vehicle fueling stations • vehicle service and maintenance facilities • vehicle and equipment cleaning facilities • fleet storage areas (bus, truck, etc.) • industrial sites • marinas (service and maintenance) • outdoor liquid container storage • outdoor loading/unloading facilities • public works storage areas • facilities that generate or store hazardous materials • commercial container nurseries • other land uses and activities designated by appropriate permitting authorities of Hawaii

3.3.2 General Performance Standards

To prevent adverse impacts of stormwater runoff, the following performance standards are recommended for all new development sites and redevelopment sites.

Standard 1 Site designs shall strive to reduce the generation of stormwater runoff by reducing impervious surfaces and utilizing pervious areas for stormwater treatment.

Standard 2 Stormwater management shall be provided through a combination of the use of structural and non-structural practices.

Standard 3 All stormwater runoff generated from new development shall be adequately treated prior to discharging into jurisdictional wetlands or inland and coastal waters of Hawaii.

Standard 4 For new development, structural stormwater best management practices (BMPs) shall be designed to remove 80% of the average annual post development total suspended solids (TSS) load and other pollutants as possible (see Section 3.4). It is presumed that a BMP complies with this performance standard if it is:

1. sized to capture the prescribed water quality volume (WQ_v),
2. designed according to the specific performance criteria outlined in this workbook,

3. constructed properly, and
4. maintained regularly.

Standard 5 Stormwater discharges to critical areas with sensitive resources (i.e., coral reefs, beaches, wellhead protection areas, designated sensitive ecosystems) may be subject to additional performance criteria, as directed by the appropriate approval authority.

Standard 6 All BMPs shall have an enforceable operation and maintenance agreement to ensure the system functions as designed. In addition, every BMP shall have an acceptable form of water quality pretreatment.

Standard 7 Stormwater discharges from land uses or activities with higher potential pollutant loadings, defined as hotspots (see Section 3.3.1), are required to use specific structural BMPs and pollution prevention practices.

3.3.3 Treatment Criteria

The treatment criteria have been determined based on similar work on the mainland, as well as the local precipitation characteristics. While the methodology is consistent across all land uses and all receiving water types, the specific sizing requirements are different for areas of the Hawaiian Islands with differing annual precipitation.

Water Quality Criteria (WQ_v)

The water quality volume (denoted as the WQ_v) is intended to improve water quality by capturing and treating the small, frequently occurring storm events. The WQ_v is directly related to the amount of impervious cover created at a site.

The following steps can be used to determine the water quality storage volume WQ_v:

1. Define Site Area and Impervious Cover

Designers should measure site area and impervious cover directly from the site plan. For operational purposes, impervious cover (I) is defined as any area of the site that is not covered by vegetation and is expressed as a percentage.

2. Compute Runoff Coefficient for Site

The volumetric runoff coefficient is defined based on the following equation:

$$R_v = 0.05 + 0.009\ (I)$$

3. Determine Appropriate Water Quality Storm (S)

Given that annual rainfall ranges from 10 to almost 500 inches on the Hawaiian Islands, designers should consult a precipitation map to determine the estimated annual rainfall for their site. Then, the appropriate water quality storm depth can be selected from Table 3.2 below:

Table 3.2 Water Quality Storm Depth Based on Annual Rainfall (AR)

Zone No. 1	*Zone No. 2*	*Zone No. 3*
AR < 25 inches	AR 26 to 74 inches	AR > 75 inches
S = 0.8 inches	S = 1.0 inch	S = 1.5 inches

4. Compute Water Quality Volume (WQ_v)

The Water Quality Volume (WQv) expresses the cubic feet of runoff that must be treated in an acceptable stormwater treatment practice and is computed as:

$$WQ_v = (R_v)\ (S)\ (A)\ (3630)$$

Where = A = total site area, in acres

5. Select Appropriate Best Management Practice (BMP)

The designer then selects which of the stormwater BMPs can meet the WQ_v requirement. The design guidelines for specific practices presented later in this document contain simple sizing equations to determine how to achieve the WQ_v at a site.

For facility sizing criteria, the basis for hydrologic and hydraulic evaluation of development sites should be as follows:

- Impervious cover is measured from the site plan and includes all impermeable surfaces (i.e., paved roads, driveways and yards, parking lots, sidewalks, rooftops, patios, and decks).
- The final WQ_v shall be treated by an acceptable stormwater best management practice (BMP), with consideration to the management priorities of the given receiving waters. The list of acceptable BMPs and receiving waters management criteria are presented in Section 3.4.
- Off-site areas shall be assessed based on their "pre-developed condition" for computing the water quality volume (i.e., treatment of only on-site areas is required). However, if an offsite area drains to a proposed BMP, flow from that area must be accounted for in the sizing of a specific practice.

3.4 Acceptable Best Management Practices (BMPs)

This section outlines minimum design criteria for five groups of structural best management practices (BMPs) to meet water quality treatment goals. Some information for this section was based on work by Schueler (2006) for the County of Maui, Hawaii. The practice groups include ponds/wetlands, infiltration practices, filtering systems and open channels. The acceptable practices in this chapter were selected based on the following criteria:

1. Can capture and treat the full water quality volume (WQ_v)
2. Are capable of approximately 80% total suspended solids (TSS) removal*
3. Are capable of meeting management objectives for specific resource protection areas through elevated total phosphorus (TP), total nitrogen (TN) and/or fecal coliform bacteria (FC) removal**
4. Have acceptable longevity in the field.

* The 80% removal target is a management measure developed by EPA as part of the Coastal Zone Act Reauthorization Amendments of 1990. It was selected by EPA for the following factors: (1) removal of 80% is assumed to control heavy metals, phosphorus, and other pollutants; (2) a number of mainland U.S. states including DE, FL, TX, MA, ME, MD, and VT require/recommend TSS removal of 80% or greater for new development; and (3) data show that certain BMPs, when properly designed and maintained, can meet this performance level.

** The TP, TN and FC removal capabilities for those practices that are also capable of removing 80% TSS will dictate their application for those conditions where additional nutrient and/or bacteria removal is required.

This chapter also provides minimum design criteria and guidance for structural management options for pretreatment. Pretreatment BMPs are designed to improve water quality and enhance the effective design life of practices by consolidating sedimentation location, but cannot meet the pollutant removal targets. Pretreatment practices must be combined in a "treatment train" with other water quality BMPs to meet the water quality criteria.

These design guidelines were developed as a consequence of a reconnaissance of development and climatic conditions on the island, and with input from local developers, engineering consultants and municipal staff. The guiding philosophy was to develop:

- Relatively short and simple guidance on a limited number of best management practices;
- Design criteria that are specifically adapted to work under the unique constraints and conditions on the islands; and
- Specifications that use construction materials and plant stock that are readily available on the island.

3.4.1 Acceptable Water Quality Practice List

Acceptable practices are divided into four broad groups, including:

- Stormwater Ponds/ Wetlands — Practices that have a combination of permanent pool and extended detention capable of treating the WQ_v.

- Infiltration Practices — Practices that capture and temporarily store the WQ_v before allowing it to infiltrate into underlying soils.

- Filtering Practices — Practices that capture and temporarily store the WQ_v before passing it through a filter bed of sand, organic matter, soil, or other media.

- Open Channel Practices — Practices explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means, or within the channel itself through a slow velocity and relatively long residence time.

Table 3.3 below lists and describes the BMPs in each of the groups that are acceptable to capture and treat the full WQ_v.

Table 3.3 List of BMPs Acceptable for Water Quality

Group	Practice	Description
Ponds/Wetlands	Micropool Extended Detention Pond	Pond that treats the majority of the water quality volume through extended detention, and incorporates a micropool at the outlet of the pond to prevent sediment resuspension.
	Extended Detention/Shallow Wetland	A pond/wetland system that provides a portion of the water quality volume by detaining storm flows above the marsh surface.
	Wet Extended Detention Pond	Pond that treats a portion of the water quality volume by detaining storm flows above the permanent pool for a specified minimum detention time.
Infiltration	Infiltration Trenches/Chambers	An infiltration practice that stores the water quality volume in the void spaces of a limestone aggregate trench or within an open chamber before it is infiltrated into underlying soils within the B or C soil horizons.
Filtering Practices	Sand/organic Filter	A filtering practice that treats stormwater by settling out larger particles in a sediment chamber, and then filtering stormwater through a surface, underground, or perimeter sand or organic matrix.
	Bioretention	A shallow depression that treats stormwater as it flows through a soil matrix, and is returned to the storm drain system, or infiltrated into underlying soils or substratum.
Open Channels	Dry Swale	An open vegetated channel or depression explicitly designed to detain and promote filtration of stormwater runoff into an underlying fabricated soil matrix.
	Oversized Swale	An open vegetated channel designed to trap sediment above the surface of the swale.
	Amended Grass Channel	An open vegetated channel with thin layer of topsoil, compost, sand, lime and erosion control fabric to help establish dense grass cover.

See Section 3.5 for presumed pollutant removals of the practice groups as guidance on appropriate BMP selection.

Limited design guidance and specifications are provided in this manual for these practices. In addition, a number of proprietary technologies have been developed to provide water quality treatment. Some of these have been monitored by independent sources with mixed results. The U.S. EPA and the U.S. NRCS have developed a joint manual and website describing these technologies. Individual fact sheets can be downloaded from the following source (http://www.epa.gov/NE/assistance/ceit_iti/tech_cos/stor.html).

3.4.2 Minimum Design Criteria for BMPs

This section presents design criteria for the BMPs listed above for use on the Islands of Hawaii.

3.4.2.1 Stormwater Ponds/Wetlands

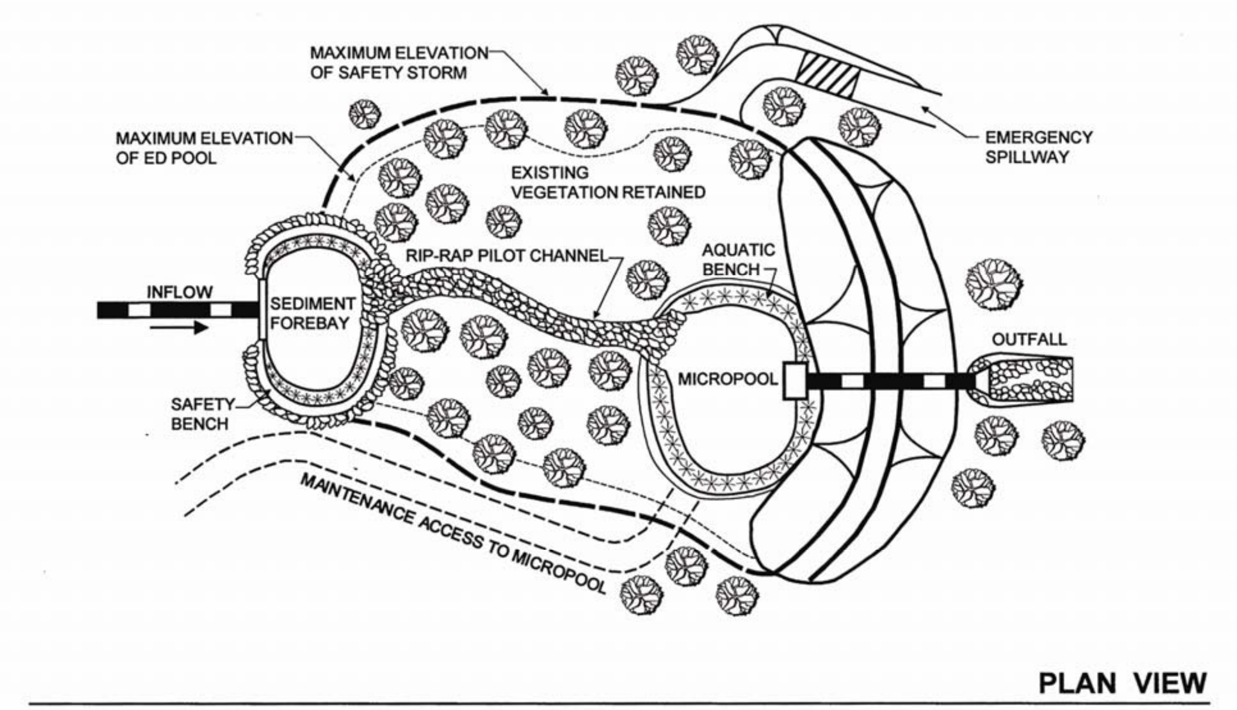
Stormwater ponds are practices that have either a permanent pool of water, or a combination of a permanent pool and extended detention, and some elements of a shallow marsh equivalent to the entire WQ_v. Three design variants include:

- P-1 Micropool* Extended Detention** Pond (Figure 3.5)
- P-2 Extended Detention Shallow Wetland (Figure 3.6)
- P-3 Wet Extended Detention Pond (Figure 3.7)

Treatment Suitability:
All stormwater pond design variations can be used to provide storage for quantity requirements as well.

NOTE:
Any practice that creates an embankment is required to follow the local dam requirements. Graphics adopted from CWP, 2002 (Vermont Stormwater Management Manual).

* Micropool is the term to define a small permanent pool 4-8 feet deep, typically with a minimum storage of 0.1 inches per impervious acre of drainage.
** Extended detention involves providing temporary storage above the permanent pool or micropool for at least a portion of the WQ_v that is released over a specified period of time (i.e., 24 hours).



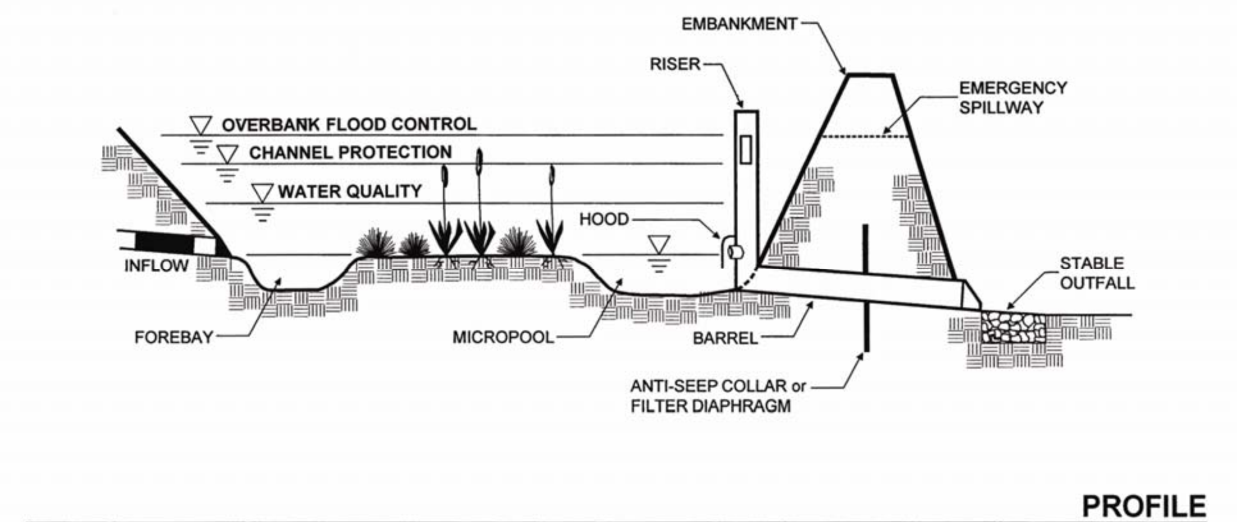


Figure 3.5 Micropool Extended Detention Pond (P-1)

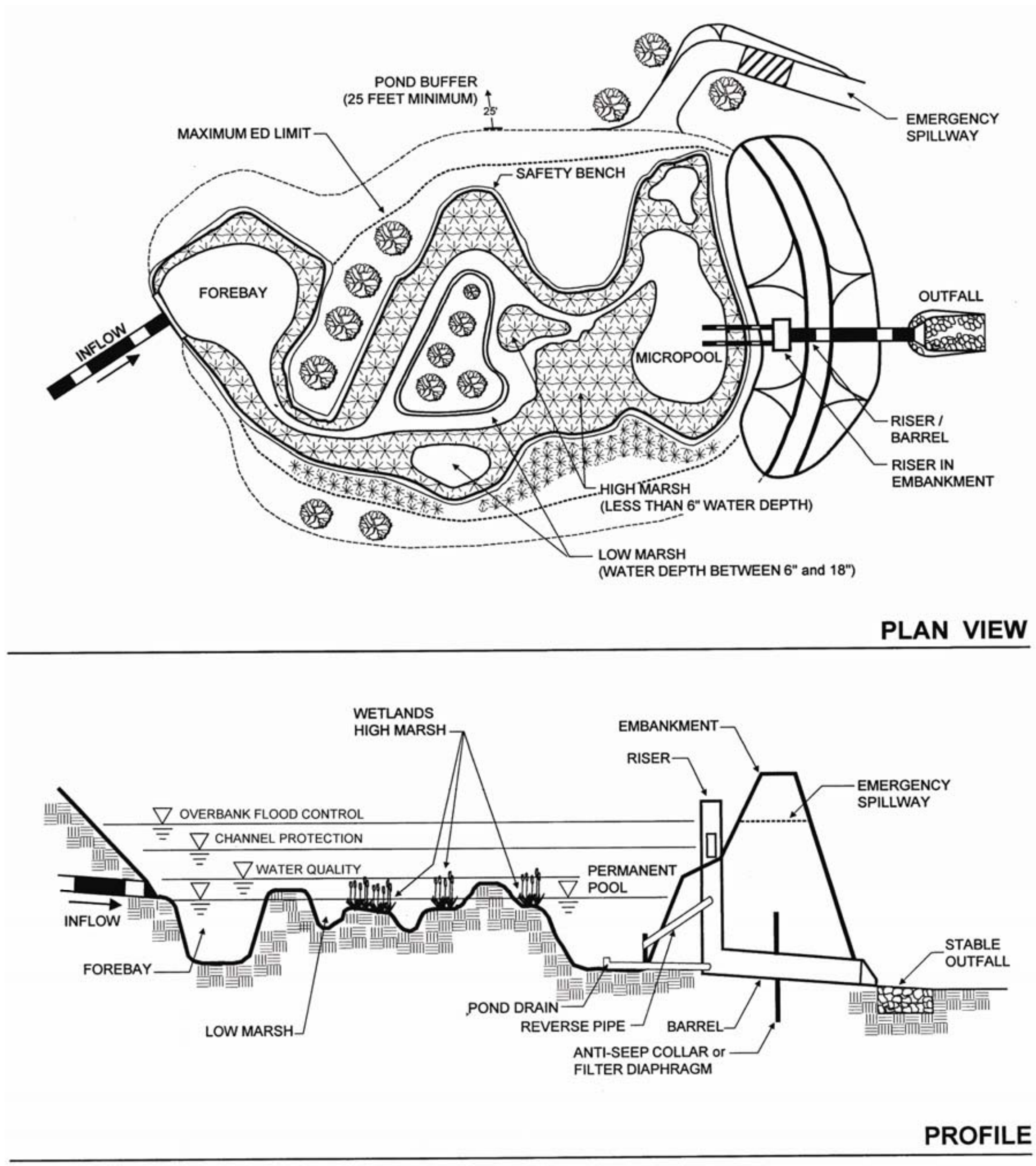


Figure 3.6 Extended Detention Shallow Wetland (P-2)

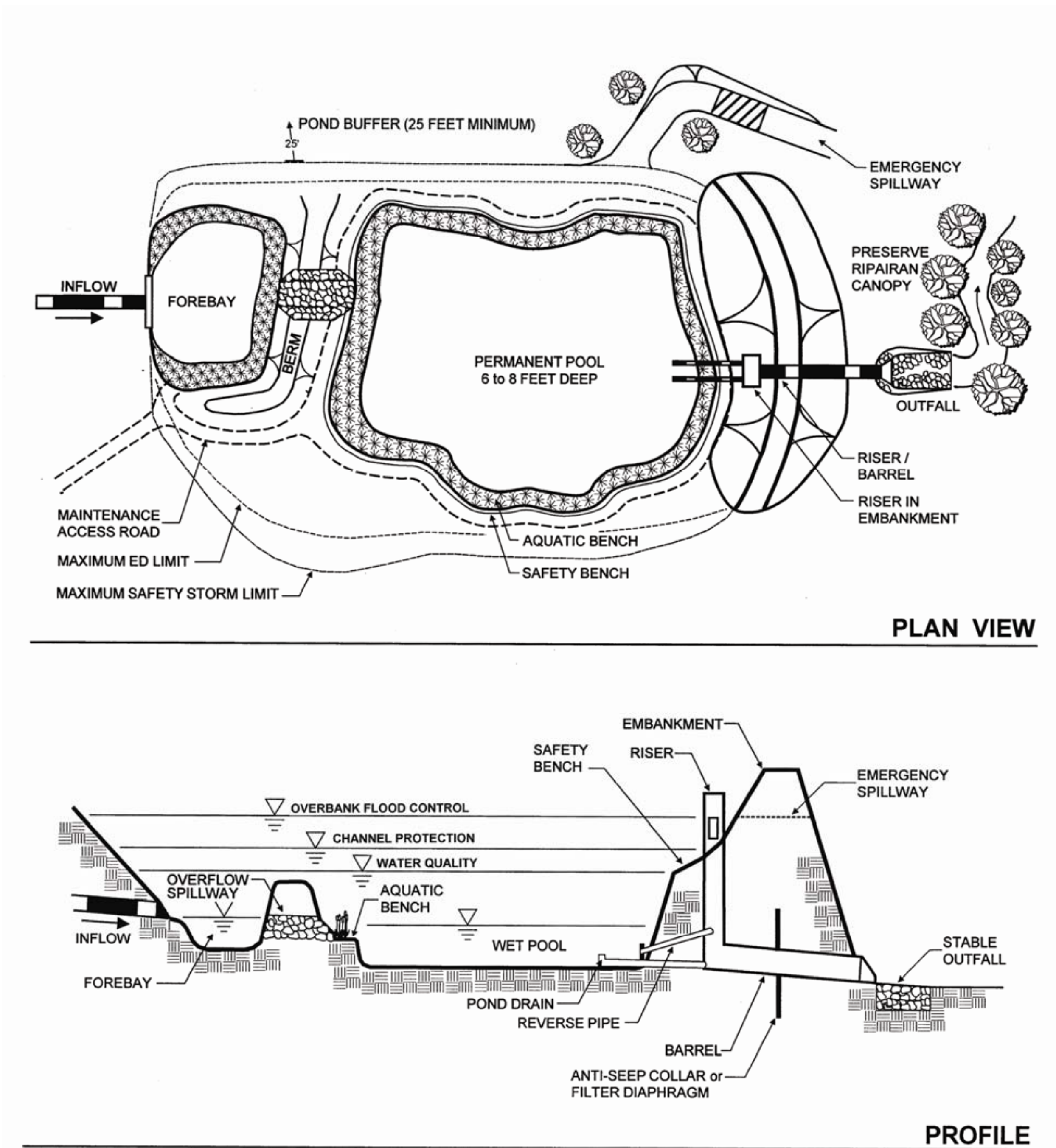


Figure 3.7 Wet Extended Detention Pond (P-3)

Island Adaptations

- The term stormwater pond and wetland are used interchangeably in this guidance. Ponds generally have deeper permanent pools, while wetlands have shallow ones, but both pond and wetland design features (along with extended detention) will be used together in most sites.

- High soil permeability and high annual evaporation rates make it difficult to maintain a constant permanent pool in many parts of the island; therefore, it is important to directly address fluctuating water levels in design. Soil infiltration tests need to be conducted at proposed pond sites to determine the need for a pond liner, or other methods to address water level fluctuation.

- Pond and wetland design is strongly influenced by annual rainfall. Three pond designs are proposed based on annual rainfall: micropool extended detention, shallow wetland extended detention and wet extended detention ponds.

- Stormwater quality ponds can discharge to infiltration basins or perforated pipes to provide peak discharge control, but need to be a separate, prior cell to assure full removal of pollutants prior to discharge to groundwater.

Practice Description

Stormwater ponds utilize a combination of permanent pools, shallow wetlands and temporary extended detention storage to remove pollutants. They are created by excavating an already existing natural depression or by constructing an embankment. Runoff from rain events is detained and treated in the pond through gravitational settling and enhanced biological uptake until it is displaced by runoff from the next storm. Permanent pools, such as a forebay or micropool, serve to protect deposited sediments from being resuspended. Temporary storage above the permanent pool may be used for temporary extended detention. Wetlands plants may colonize shallow water depths from zero to 9 inches deep.

Pollutants are removed by stormwater ponds through algal uptake, wetland vegetation, and gravitational settling. Volatilization and chemical activity can also occur, breaking down and assimilating a number of other stormwater contaminants such as hydrocarbons

Stormwater ponds are a widely applicable for most land uses, and are best suited for larger drainage areas (e.g., minimum drainage area of 10 to 25 acres depending on annual rainfall) and local soil infiltration rate). Where feasible, stormwater ponds are a cost-effective stormwater treatment practices. They are not recommended in ultra-urban areas, small drainage areas or an on-line location in a stream. With proper design and maintenance, stormwater ponds can be an attractive and even command a premium on parcels that are adjacent to them.

Stormwater ponds are also an effective practice to provide peak discharge control storage, above the permanent pool (if the discharge is to surface waters). If the discharge is ultimately to groundwater, the stormwater quality pond must be in a separate, prior cell to assure full removal of pollutants prior to discharge to groundwater (i.e., a pond within a pond). Dam safety regulations should be strictly followed with stormwater pond design to ensure that downstream property and structures are adequately protected.

Stormwater Pond and Wetland Feasibility Factors

Stormwater ponds shall not be located within jurisdictional waters, including wetlands. In some isolated cases, a permit may be granted to convert an existing degraded wetland in the context of local watershed restoration efforts. Avoid location of pond designs within the stream channel, to prevent habitat degradation caused by these structures.

- Annual Rainfall – Water quality sizing varies depending on annual rainfall—See Table 3.4.
- Drainage Area – Minimum ranges based on annual rainfall from 10 to 25 acres, See Table 3.4.
- Space Required – Most ponds require about 1-3% of the contributing drainage area for the footprint of the practice, depending on the average depth of treatment.
- Site Slope – Sloped areas immediately adjacent to the pond should be less than 20%. Slopes with the pond should be greater than 0.5 – 1% to promote positive flow through the pond practice
- Minimum Head – Elevation difference needed at a site from the inflow to the outflow ranges from 3 to 10 feet, depending on the design.
- Minimum Depth to Water Table – In general, there is no minimum separation distance required with stormwater ponds. In fact, intercepting the groundwater table is common and helps sustain a permanent pool.
- Soils – Underlying soils of hydrologic group “C” or “D” should be adequate to maintain a permanent pool. Most group “A” soils and some group “B” soils will require a liner.
- Mosquito Control – Stormwater ponds can be properly designed, constructed and maintained to minimize the likelihood of being desirable habitat for mosquito populations. Designs that incorporate constant inflows and outflows, create habitat for natural predators, and maintain constant permanent pool elevations limit mosquito breeding habitat conditions.
- Aesthetics – When ponds and wetlands are integrated early in the site planning process to provide significant aesthetic appeal to a site that can command additional lot premiums.

Pond and Wetland Design Features

The design of stormwater ponds and wetlands is strongly influenced by the annual rainfall present at an island site. Table 3.4 presents three basic design variants for ponds and wetlands on Hawaiian Islands, along with some of their key design features. In addition, designers should incorporate the following standard design features into stormwater ponds and wetlands:

Inlet Protection

- Flowpaths from the inflow points to the outflow points of stormwater wetlands shall be maximized.
- Microtopography (complex contours along the bottom of the wetland system, providing greater depth variation) is encouraged to enhance wetland diversity.
- Each inlet will be served by a forebay unless the inlet provides less than 10% of the total WQ_v to the stormwater pond.
- Inlet areas should be stabilized to ensure that non-erosive conditions exist during events up to the overbank flood event.
- Inlet areas should be stabilized to ensure that non-erosive conditions exist for at least the 1-year frequency storm event.
- Inlet pipe inverts should generally be located at or slightly below the permanent pool to limit erosive conditions.
- Reverse slope pipes should draw from at least 12" below the permanent pool.

Table 3.4: Three Design Variants for Island Ponds and Wetlands

DESIGN FACTOR	DESIGN NO. 1 (AR < 25 inches)	DESIGN NO. 2 (AR 26 to 74 inches)	DESIGN NO. 3 (AR > 75 inches)
Water Quality Volume	0.8 inch storm	1.0 inch storm	1.5 inch storm
Recommended Pond Design	Micropool Extended Detention Pond	Extended Detention/Shallow Wetland	Wet Extended Detention Pond
Permanent Pool (as a % of WQ_v)	10% for forebay and micropool only	30% for forebay, micropool and shallow wetland	50% for permanent pool
24-Hour Extended Detention	Up to 90% of WQ_v	Up to 70% of WQ_v	Up to 50% of WQ_v
Liner?	Yes, if measured infiltration rates exceed 2 inches/hour		
Minimum Drainage Area	25 acres	15 acres	10 acres
Surface Cover	Native grass	Wetland plants	Wetland benches
Sideslopes to Bench	5:1 max	4:1 max	3:1 max
Shoreline Bench	25 feet @ 5% slope	20 feet around pools	15 feet around pools
Access	To forebay, riser and micropool	To forebay, riser and micropool	To forebay and riser

Adequate Outfall Protection

- The channel immediately below the pond outfall shall be modified to prevent erosion and conform to natural dimensions in the shortest possible distance, typically by use of appropriately sized riprap placed over filter fabric that can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps).
- Outfalls should be constructed such that they do not increase erosion or have undue influence on the downstream geomorphology of the stream.
- Flared pipe sections that discharge at or near the stream invert or into a step-pool arrangement should be used at the spillway outlet.
- If a pond daylights to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance.

Stormwater Pond Liners

- When a stormwater pond is located in highly permeable soils (>2 inches/hour infiltration rate), a liner may be needed to sustain a permanent pool of water. If geotechnical tests confirm the need for a liner, acceptable options include: (a) six to 12 inches of clay soil (minimum 15% passing the #200 sieve and a minimum permeability of 1×10^{-5} cm/sec), (b) a 30 ml poly-liner (c) bentonite, (d) use of chemical additives, or (e) engineering design as approved on a case-by-case basis by the local review authority.

Sediment Forebay

- A sediment forebay is important for maintenance and longevity of a stormwater pond. The forebay shall consist of a separate cell, formed by an acceptable barrier. Typical examples include earthen berms, concrete weirs, and gabion baskets.
- The forebay shall be sized to contain 10% of the water quality volume (WQ_v), and shall be four to six feet deep. The forebay storage volume counts toward the total WQ_v requirement.
- The forebay shall be designed with non-erosive outlet conditions
- Direct access for appropriate maintenance equipment shall be provided to the forebay.
- A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition over time.
- The bottom of the forebay may be hardened (i.e., concrete, asphalt, grouted riprap) to make sediment removal easier.

Treatment

- The WQ_v may be provided by any combination of permanent pool, shallow marsh and/or extended detention storage
- At least 25% of the permanent pool volume of a stormwater wetland shall be in deepwater zones with a depth greater than four feet.

- A minimum of 35% of the total surface area of stormwater wetlands shall have a depth of six inches or less, and at least 65% of the total surface area shall be shallower than 18 inches.
- A water balance is recommended to document sufficient inflows to maintain a constant permanent pool in portions of the island receiving less than 45 inches of rain per year.
- Permanent pool storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh). A berm or simple weir should be used instead of pipes to separate multiple wetland cells.
- The extended detention associated with the WQ_v shall not extend more than five feet above the permanent pool or basin floor at its maximum water surface elevation.
- It is generally desirable to provide water quality treatment off-line when topography, head and space permit. Off-line stormwater management systems are designed to manage a storm event by diverting a percentage of stormwater events from a stream or storm drainage system.

Minimum Stormwater Pond Geometry

- The desired length to width ratio for stormwater ponds shall be a minimum 2:1 (i.e., length relative to width).
- Microtopography (small irregular 6 to 24 inch variations in bottom topography) is encouraged to enhance wetland diversity.
- Provide a minimum Drainage Area: Surface Area Ratio of 75:1.
- To the greatest extent possible, maintain a long flow path through the system, and design ponds with irregular shapes.

Stormwater Pond Benches

- The perimeter of all pool areas greater than four feet in depth shall be surrounded by two benches:
    1. Safety Bench: Except when stormwater pond side slopes are 5:1 (h:v) or flatter, provide a safety bench that generally extends 10 to 25 feet outward from the normal water edge to the toe of the stormwater pond side slope (See Table 3.4). The maximum slope of the safety bench shall be 5%; and
    2. Aquatic Bench: Incorporate an aquatic bench that generally extends up to 10 feet inward from the normal shoreline, has an irregular configuration, and a maximum depth of eighteen inches below the normal pool water surface elevation.

Landscaping Plan

A landscaping plan shall be provided that indicates the methods used to establish and maintain vegetative coverage in the pond and its buffer. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed) and sources of native plant material.

- Structures such as fascines, coconut rolls, or carefully designed stone weirs can be used to create shallow marsh cells in high-energy areas of the stormwater pond.
- Wherever possible, wetland plants should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes or within shallow areas of the pool itself.
- The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.
- Donor soils for wetland mulch shall not be removed from natural wetlands.
- The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the stormwater wetland and buffers.
- Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment and 25 feet from the principal spillway structure.

<u>Stormwater Pond Buffers and Setbacks</u>

- A buffer should be provided that extends 25 feet outward from the maximum water surface elevation of the stormwater pond. Permanent structures (e.g., buildings) should not be constructed within the buffer. Existing trees should be preserved in the buffer area during construction. The pond buffer shall be contiguous with other buffer areas that are required by other regulations. An additional setback may be provided to permanent structures.
- Existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help encourage reforestation, the buffer can be planted with trees, shrubs and native ground covers.
- Woody vegetation may not be planted or allowed to grow on an earthen dam embankment, within 15 feet of the toe of the embankment or 25 feet from the principal spillway outlet structure.
- The soils in the stormwater buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration, and therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the rootball (of balled and burlap stock), and five times deeper and wider for container grown stock. Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds.
- Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as rangeland (mowing every other year) or forest.

<u>Maintenance Access</u>

- A maintenance right of way or easement shall extend to a stormwater pond from a public or private road.

- Maintenance access should be at least 12 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles. Steeper grades are allowable with stabilization techniques such as a gravel road.
- The maintenance access should extend to the forebay, safety bench, riser, and outlet and be designed to allow vehicles to turn around.

Non-clogging Low Flow Orifice

- A low flow orifice shall be provided that is adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3") or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice of 1").
- The preferred method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point one foot below the normal pool elevation.
- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool.
- The use of horizontally extended perforated pipe protected by geotextile fabric and limestone aggregate is not recommended. Vertical pipes may be used as an alternative if a permanent pool is present.

Riser in Embankment

- The riser should be located within the embankment for maintenance access, safety and aesthetics. In addition, the riser should be located so that short-circuiting between inflow points and the riser does not occur.
- Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

Pond Drain

- Except where local slopes prohibit this design, each stormwater pond should have a drain pipe that can completely or partially drain the permanent pool. The drain pipe should have an elbow or protected intake within the pond to prevent sediment deposition, and a diameter capable of draining the pond within 24 hours.

Safety

- The principal spillway opening shall not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter shall be fenced to prevent a hazard.
- An emergency spillway and associated freeboard shall be provided in accordance with applicable Hawaii dam safety requirements. The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Side slopes to the pond shall not exceed 3:1 (h:v), and shall terminate on a safety bench.

- Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.
- Warning signs prohibiting swimming may be posted.
- Stormwater pond fencing is generally not encouraged, as the preferred method is to manage the contours of the stormwater pond to eliminate drop-offs or other safety hazards.

<u>Pond Maintenance</u>

Maintenance is needed so stormwater ponds continue to operate as designed on a long-term basis. Some important post construction maintenance considerations are provided below.

- A legally binding and enforceable maintenance agreement should be executed between the pond owner and the local review authority.
- Adequate access must be provided for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles.
- The principal spillway shall be equipped with a removable trash rack, and generally accessible from dry land.
- Sediment removal in the forebay should occur every 2 to 7 years or after 50% of total forebay capacity has been lost.
- Sediments excavated from stormwater ponds that do not receive runoff from confirmed hotspots are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be required prior to sediment disposal when a hotspot land use is present (see Section 3.3.1 for a list of potential hotspots).
- Periodic mowing of the stormwater buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.
- Inspections during construction are needed to ensure that the practice is built in accordance with the approved design and standards and specifications.

Stormwater pond maintenance activities range in terms of the level of effort and expertise required to perform them. Routine stormwater pond maintenance, such as mowing and removing debris or trash, is needed several times each year (See Table 3.5). More significant maintenance such as removing accumulated sediment is needed less frequently, but requires more skilled labor and special equipment. Inspection and repair of critical structural features such as embankments and risers, needs to be performed by a qualified professional (e.g., structural engineer) that has experience in the construction, inspection, and repair of these features.

Table 3.5: Typical Maintenance Inspection Frequencies for Stormwater Pond/Wetlands

Inspection Items	Maintenance Items	Frequency
▪ Ensure that at least 50% of wetland plants survive ▪ Check for invasive wetland plants.	▪ Replant wetland vegetation	One time - After First Year
▪ Inspect low flow orifices and other pipes for clogging ▪ Check the permanent pool or dry pond area for floating debris, undesirable vegetation. ▪ Investigate the shoreline for erosion ▪ Monitor wetland plant composition and health. ▪ Look for broken signs, locks, and other dangerous items.	▪ Mowing – twice a year ▪ Remove debris ▪ Repair undercut, eroded, and bare soil areas.	Monthly to Quarterly or After Major Storms (>1")
▪ Monitor wetland plant composition and health. ▪ Identify invasive plants ▪ Mechanical components are functional	▪ Trash and debris clean-up day ▪ Remove invasive plants ▪ Harvest wetland plants ▪ Replant wetland vegetation ▪ Repair broken mechanical components if needed	Semi-annual to annual
▪ All routine inspection items above ▪ Inspect riser, barrel, and embankment for damage ▪ Inspect all pipes ▪ Monitor sediment deposition in facility and forebay	▪ Pipe and Riser Repair ▪ Forebay maintenance and sediment removal when needed	Every 1 to 3 years
▪ Monitor sediment deposition in facility and forebay	▪ Forebay maintenance and sediment removal when needed	2-7 years
▪ Remote television inspection of reverse slope pipes, underdrains, and other hard to access piping	▪ Sediment removal from main pond/wetland ▪ Pipe replacement if needed	5-25 years

3.4.2.2 Stormwater Infiltration

Stormwater infiltration practices capture and temporarily store the WQ_v before allowing it to infiltrate into the soil over a two-day period. Design variants include:

- I-1 Infiltration Trench/Chamber (Figure 3.8)

Treatment Suitability: Infiltration practices typically cannot provide storage for quantity requirements, except on sites where the soil infiltration rate is greater than 5.0 in/hr. Extraordinary care should be taken to assure that long-term infiltration rates are achieved through the use of performance bonds, post construction inspection and long-term maintenance. Infiltration within geologic formations that may have very high permeability rates may allow for infiltration of large volumes of stormwater. Applicants must provide pretreatment of 100% of the WQ_v prior to direct infiltration into these formations. Roof runoff can be infiltrated directly, without treatment, and counted toward WQ_v requirements.

NOTE: Graphics adopted from CWP, 2002.

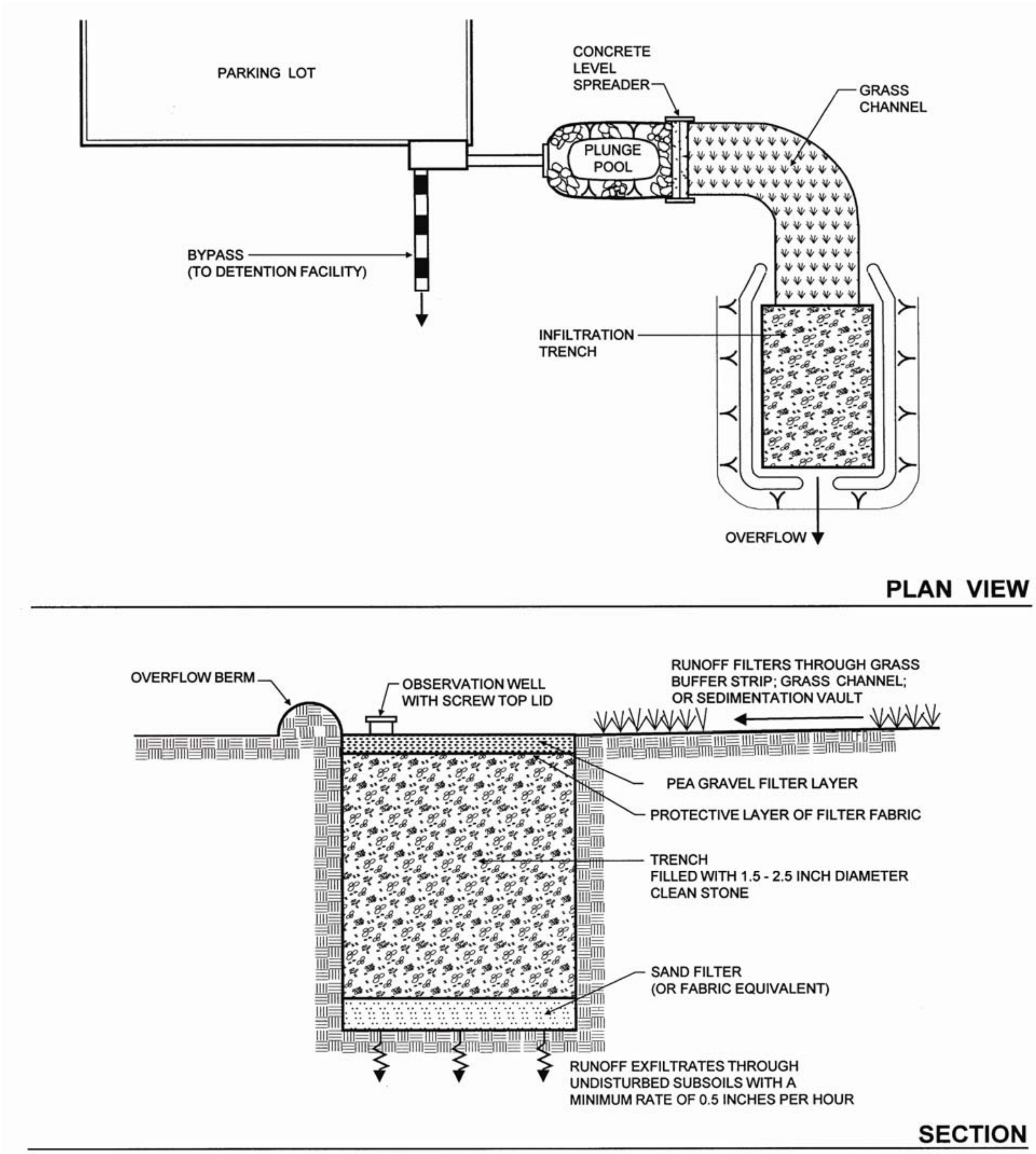


Figure 3.8 Infiltration Trench/Chamber (I-1)

Island Adaptations

- Most island soils are conducive to rapid infiltration rates, regardless of whether they are of volcanic or limestone origin. Depending on annual rainfall, up to three different infiltration designs can be used.
- For water quality purposes, all infiltration trenches need to be in the soil horizon (i.e., above bedrock) and installed after construction has ceased and the site is vegetated and stabilized. While underground infiltration is commonly used on the island to deal with stormwater detention/disposal, infiltration trenches used for stormwater pollution control must be located within the surface soils.
- Trenches or chambers need to include surface pretreatment cell capable of keeping sediment and vegetation out of the infiltration cell.
- Due to thin soils and safety considerations, trench depths greater than 5 feet are not recommended.
- Designers need to measure on-site soil infiltration site, and assess future operations at the proposed site to determine if they may be a potential stormwater hotspot. No hotspot runoff can be infiltrated under any circumstances.

Practice Description

An infiltration trench is a rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through a pretreatment cell where sediment and organic matter are trapped before entering the trench. There, runoff is stored in the voids of the stones, and infiltrates into the underlying soil matrix. Plastic arch chambers or other comparable perforated storage material can be used in conjunction with stone to increase the available underground storage. Observation wells are incorporated to monitor clogging and infiltration rates over time.

Stormwater infiltration trenches capture and temporarily store stormwater before allowing it to infiltrate into the soil. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where measured soil permeability rates exceed one inch per hour. Infiltration trenches are also suitable for many linear projects such as roadways. The infiltration trench design uses two surface cells- the first is used to trap and store sediments while the second is where runoff is infiltrated into the soil.

Infiltration trenches are primarily used for water quality treatment, but can be connected to larger underground perforated pipes used to detain peak discharges. Otherwise, infiltration trenches should either be designed “off-line” using a flow diversion or designed to safely pass large storm flows while still protecting the infiltration area.

Feasibility of Infiltration at Sites

Sites where infiltration is planned require careful analysis to define design constraints, as follows:

- Drainage Area – The contributing area draining to an individual infiltration trench should be stabilized and less than 2 acres in area.
- Space Required – Varies depending on the depth of the practice. Generally infiltration trenches are three to five feet deep and less than 25 feet wide.
- Site Slopes –Unless slope stability calculations demonstrate otherwise, infiltration trenches should be located a minimum horizontal distance of 200 feet from down gradient slopes greater than 20%. Contributing drainage areas should limit slopes to 15%.
- Practice Slope - Infiltration trench bottoms should be flat to enable even distribution and infiltration of stormwater. A zero percent longitudinal slope is recommended, with a maximum longitudinal slope of 1%. Lateral slopes should be 0%.
- Minimum Head – Elevation difference needed at a site to operate an infiltration trench is nominal- about one foot.
- Minimum Depth to Water Table – Infiltration practices should provide a minimum vertical distance of 3 feet between the bottom of the infiltration practice and the seasonal high water table or bedrock layer.
- Soils - Native soils in proposed infiltration areas must have a minimum infiltration rate of 1.0 inches per hour (typically Hydrologic Soil Group A, with some B soils). Initially, soil infiltration rates can be estimated from NRCS soil data, and confirmed with an on-site infiltration evaluation. Native soils should have silt/clay contents less than 40% and clay content less than 20%. Infiltration practices should not be situated above fill soils.
- Site Location – Infiltration practices should not be hydraulically connected to structure foundations or pavement to avoid seepage concerns. At a minimum, infiltration practices should be located a horizontal distance of 100 feet from any water supply well, and 35 feet from septic systems or structures.
- Groundwater Protection – Runoff from stormwater hotspots should never be infiltrated.
- Aesthetics – Infiltration trenches can be effectively integrated into the site planning process, and aesthetically designed with adjacent native landscaping.

General Design

The design of infiltration trenches is influenced by the annual rainfall and local infiltration rate, as shown in Tables 3.6 and 3.7.

Table 3.6: Water Quality Volume for Infiltration Based on Annual Rainfall (AR)

Zone No. 1	Zone No. 2	Zone No. 3
AR < 25 inches	AR 26 to 74 inches	AR > 75 inches
0.8 inch storm	1.0 inch storm	1.5 inch storm

Table 3.7: Three Design Variants for Island Infiltration Practices

DESIGN FACTOR	DESIGN NO. 1 (1.0 - 2.0 inches/hr)	DESIGN NO. 2 (2 to 4 inches/hr)	DESIGN NO. 3 (> 4 inches/hr)
Pretreatment Volume	25% of WQ_v (inclusive)	35% of WQ_v (inclusive)	50% of WQ_v (inclusive)
Pretreatment Cell	Surface cell at least two feet deep with impermeable liner and one-inch pea gravel or pumice stone surface with direct access for maintenance and sediment removal.		
Buffer Vegetation	Irrigated grass	Irrigated grass	Grass
Trench Bottom	6" sand layer		
Trench Surface	Pumice	Pea Gravel/ Washed Limestone	Pea Gravel/ Washed Limestone
Observation Well	One vertical 6" Schedule 40 PVC perforated pipe, with cap.		
Vegetation	Keep adjacent vegetation from forming an overhead canopy over trench to keep vegetation, fruits and other material from clogging trench.		
Connection to Underground Perforated Pipes	Overflow may be directed to perforated pipes after discharge only if runoff has gone through the pretreatment cell.		

<u>Conveyance</u>

- To avoid damage from the erosive velocities of stormwater flows exceeding the capacity of an infiltration system, an overflow mechanism such as a elevated drop inlet or flow splitter should be used to redirect flows to an overflow channel or stabilized water course, and be located off-line from primary storm drain conduits.
- To maintain non-erosive conditions, flows exiting and entering the infiltration practice should be between 3.5 to 5.0 feet per second.
- Infiltration practices should be sized to fully de-water the entire WQ_v within 48 hours after a storm event.

<u>Pretreatment</u>

- Infiltration trenches must include a pretreatment practice, such as a plunge pool, sump pit, or sediment basin. Depending on the infiltration rate, a proportion of the water quality volume must be pretreated, as shown in Table 3.7.
- Infiltration trenches can have redundant methods to protect the long-term integrity of the infiltration rate. Three or more of the following techniques must be installed for infiltration chambers or trenches: grass channel, grass filter strip (minimum 20 feet and only if sheet flow is established and maintained), bottom sand layer, upper sand layer (6" minimum with filter fabric at the sand/limestone aggregate interface), and use of washed, rounded stone or limestone as aggregate (1/8" to 3/8").

- Pretreatment practices should be designed such that exit velocities from the pretreatment systems are non-erosive and evenly distribute flows across the width of the practice (e.g., using a level spreader).

<u>Treatment</u>

- Infiltration practices are best used in conjunction with other practices, and often downstream detention is still needed to meet the quantity requirements.
- Infiltration practices should not be used on sites receiving continuous flow from groundwater, sump pumps, or irrigation nuisance water.
- The bottom surface area of each practice should be designed to infiltrate the entire WQ_v for the area draining to the practice (i.e., sides of the practice should not be considered in the sizing).
- The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface.
- Infiltration trenches should not be deeper than the longest surface area dimension and should generally not exceed 5 feet in depth.
- A porosity value (V_v/V_t) of 0.4 can be used to design stone reservoirs for infiltration practices.
- Calculate the surface area of infiltration trenches as:

$$A_p = V_W / (nd_t + f_c T/12)$$

Where:

A_p	=	surface area (sf)
V_W	=	design volume (e.g., WQ_v) (cf)
n	=	porosity of limestone aggregate fill (assume 0.4)
d_t	=	trench depth (maximum of five feet, and separated at least three feet from seasonally high groundwater) (ft)
f_c	=	measured infiltration rate (in/hr)
T	=	time to fill trench (hours) (assumed to be 2 hours for design purposes)

- Calculate the design volume of infiltration chambers as:

$$Vw = L*[(w*d*n) – (\#*Ac*n) + (\#*Ac) + (w*f_c*T/12)]$$

Where:

Vw	=	design volume (e.g., WQ_v) (cf)
L	=	length of infiltration facility (feet)
w	=	width of infiltration facility (feet)
h	=	depth of infiltration facility (feet)
#	=	number of rows of chambers
Ac	=	cross-sectional area of chamber (see manufacturer's specifications)
n	=	porosity (assume 0.4)
f_c	=	infiltration rate (in/hr)

T = time to fill chambers (hours) (assumed to be 2 hours for design purposes)

- Infiltration trench aggregate should consist of graded 2 to 5 inch diameter clean, washed rock with a smaller substrate material (pea gravel or washed, rounded limestone) and placed above it to prevent the aggregate from clogging. Permeable filter fabric shall be installed on the trench sides to prevent soil piping, but not on trench bottom (use sand as filter, instead).

Landscaping

- Infiltration practices should NEVER be installed until all upgradient construction is completed AND pervious areas are stabilized by dense and healthy vegetation.
- Vegetation associated with infiltration trench buffers should be regularly mowed and maintained to keep organic matter out of the trench and maintain enough native vegetation to prevent soil erosion from getting into the trench.

Safety

- Infiltration trenches do not pose any major safety hazards after construction. If an infiltration trench is greater than five feet deep, OSHA health and safety guidelines need to be consulted for safe construction practices.
- Fencing of infiltration trenches is neither necessary nor desirable.

Maintenance

Maintenance is a crucial element to ensuring the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging caused by organic matter and sediment. Common operational problems include:

- Clogging and sediment deposition
- Erosion of contributing land or in channels leading to the practice
- Maintaining appropriate surface vegetation

Table 3.8 provides a summary of common maintenance problems for infiltration trenches, and Table 3.9 outlines common maintenance activity schedules to prevent them.

Table 3.8. Typical Maintenance Problems for Infiltration Practices

Problem	Comments
Clogging, sediment deposition	Key issue for infiltration practice, requires dedicated pretreatment cell to capture sediments, and sand filter layer on trench bottom
Surface Vegetation	Important to keep woody vegetation from growing over the surface of the trench.
Erosion from upland areas	In these practices, it is important to monitor not only the practice itself, but also upland infiltration to minimize the sediment load.
Damage to filter fabric	Infrequent but important maintenance concern.
Scouring at Inlet	Need to promote non-erosive flows that are evenly distributed
Access Issues	Need surface access to pretreatment and infiltration cells for regular inspection and maintenance. Observation well is needed to check for clogging

Several steps in the design and construction of infiltration trenches can increase their longevity, minimize the maintenance burden and maintain pollutant removal efficiency.

For example, every infiltration trench design should include an observation well consisting of an anchored six-inch diameter perforated PVC pipe fitted with a cap to facilitate periodic inspection and maintenance. A legally binding and enforceable maintenance agreement should be executed between the practice owner and the local review authority. Adequate access must be provided for all infiltration practices for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles. Chambers should not be located underneath pavement unless site constraints exist.

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed. Critical construction elements for infiltration practices are as follows:

- Avoid excessive compaction- Heavy equipment and traffic should avoid traveling over the proposed location of the infiltration practice to minimize compaction of the soil.
- Keep infiltration practices "off-line" until construction is complete- Infiltration practices should never serve as a sediment control device during site construction phase and sediment should be prevented from entering the infiltration site

Table 3.9 Typical Maintenance Activities for Infiltration Trenches

Activity	Schedule
• Replace pea gravel/topsoil and top surface filter fabric (when clogged).	As needed
• Ensure that contributing area, practice and inlets are clear of debris. • Ensure that the contributing area is stabilized. • Remove sediment and oil/grease from pretreatment devices, as well as overflow structures. • Mow grass filter strips should be mowed as necessary. Remove grass clippings. • Repair undercut and eroded areas at inflow and outflow structures	Monthly
Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. • Inspect pretreatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the trench.	Semi-annual Inspection
Clean out accumulated sediments from pretreatment cell	Annually
Perform total rehabilitation of the trench to maintain design storage capacity. • Excavate trench walls to expose clean soil.	Upon Failure

- Stabilize vegetation before and after construction - excessive sediment loadings can occur without the use of proper erosion and sediment control practices during the construction process. Upland drainage areas need to be properly stabilized with a thick layer of vegetation, particularly immediately following construction, to reduce sediment loads. If infiltration practices are in-place during construction activities, diversion berms around the perimeter of the practice and soil stabilization with vegetation can help protect the practice.
- Correctly install filter fabric on trench sides - large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum top overlap. The filter fabric itself should be tucked under the sand layer on the bottom of the infiltration trench, and stones or other anchoring objects should be placed on the fabric at the trench sides to keep the trench open during windy periods. Voids

may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in any voids to ensure fabric conformity to the excavation sides.

- Establish turf cover ten feet on each side of trench - establishing dense turf on the sides of the trench to reduce erosion and sloughing, and also provides a natural means of maintaining relatively high infiltration rates. The use of native grasses is recommended for seeding primarily due to their adaptability to local climates and soil conditions. Modest irrigation may be needed in low rainfall zones to sustain grass cover.
- Inspections during construction are needed to ensure that the infiltration practice is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction to ensure that the contractor's interpretation of the plan is acceptable to the designer.
- Effective long-term operation of infiltration practices requires a dedicated and routine maintenance schedule with clear guidelines and schedules.

3.4.2.3 Stormwater Filtering Systems

Stormwater filtering systems capture and temporarily store the WQ_v and pass it through a filter bed of sand, organic matter, or soil. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially exfiltrate into the soil. Design variants include:

F-1	Sand Filter	(Figure 3.9)
F-2	Organic Filter	(Figure 3.10)
F-3	Bioretention	(Figure 3.11)

Treatment Suitability: Filtering systems should not be designed to meet runoff quantity requirements, except under extremely unusual conditions. Filtering practices shall generally be combined with a separate facility to provide those controls.

NOTE: Graphics adopted from CWP, 2002.

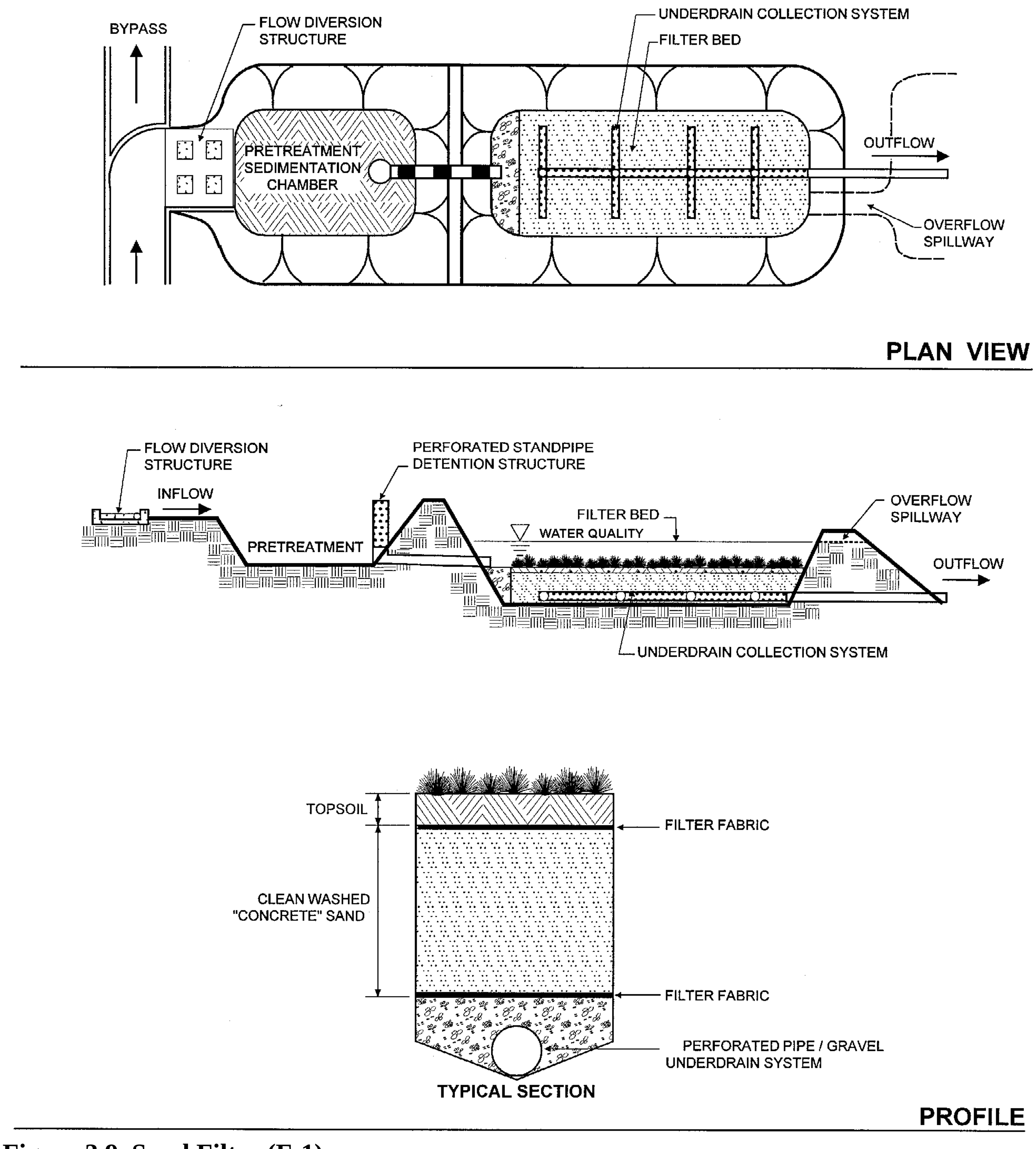


Figure 3.9 Sand Filter (F-1)

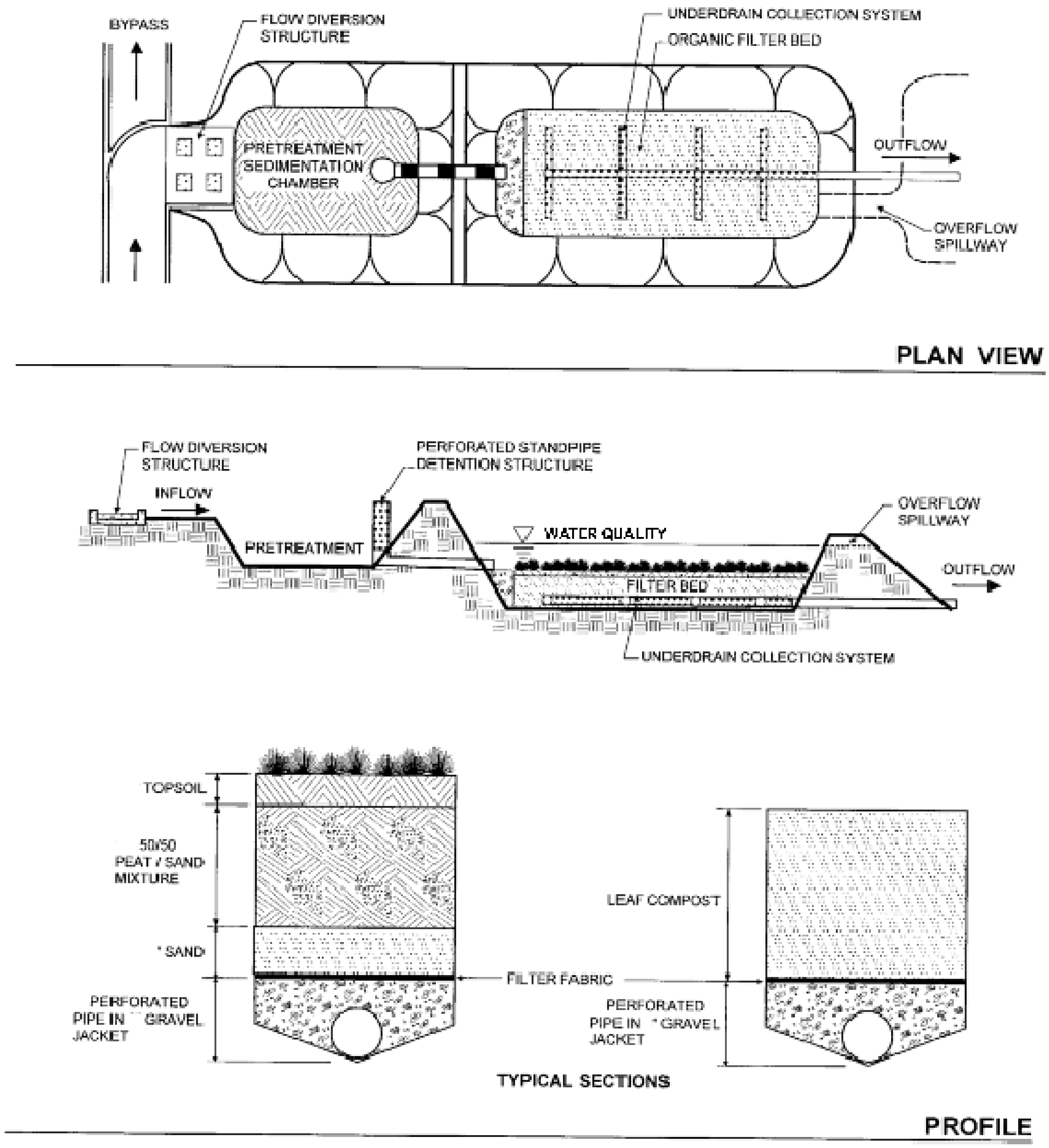


Figure 3.10 Organic Filter (F-2)

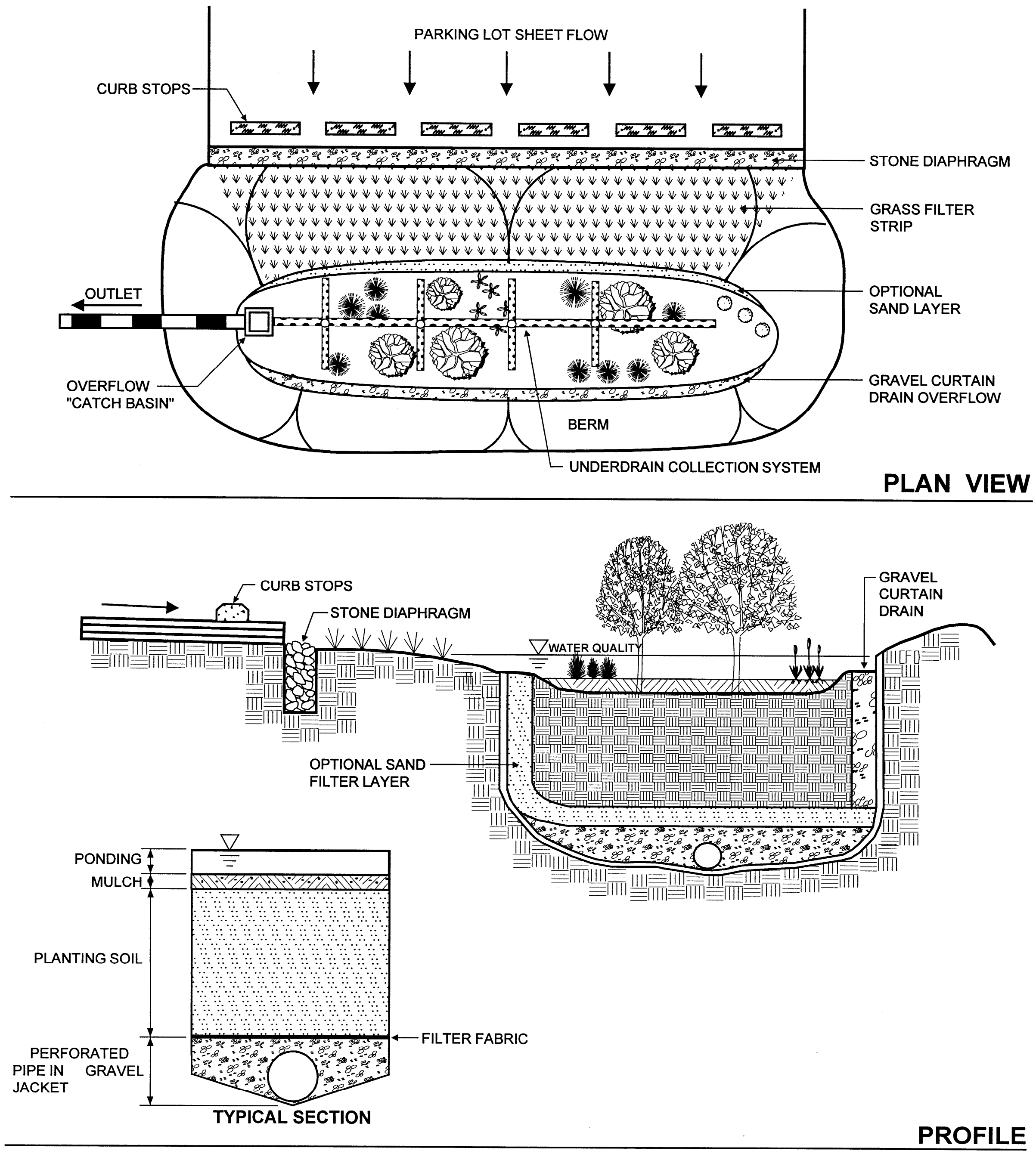


Figure 3.11 Bioretention (F-3)

Island Adaptations

- Need a two-cell design to capture sediments prior to treatment in a filtering practice.
- Thinner filter media depths recommended due to local soils and bedrock concerns.
- High ET rates make it difficult to attain a vigorous plant cover without irrigation (which is not a wise use of scarce island freshwater resources).
- Three different bioretention designs proposed that are adapted to different annual rainfall regimes on island.
- Bioretention areas must be fully protected during construction, and only installed after entire contributing drainage areas are stabilized.

Filtering practices are suitable for all land uses, so long as the contributing drainage area is limited to a maximum of about five acres. Sand and organic filters are effective for treating runoff from urban areas with high pollutant loads and can be incorporated easily into parking lots. Common bioretention opportunities include landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, and streetscapes (i.e., between the curb and sidewalk). Bioretention, when designed with an underdrain and liner is also a good design option for treating potential stormwater hotspots. Bioretention is extremely versatile because of its ability to be incorporated into landscaped areas.

Water Quality – Filtering practices are excellent stormwater treatment BMPs since they utilize a variety of pollutant removal mechanisms including vegetative filtering, settling, evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption. Filtering BMPs can also be designed as an effective infiltration/recharge practice, particularly when soil tests indicate an infiltration rate exceeding one inch per hour.

Peak Discharge Control - To meet quantity control, another structural control (e.g., detention) will be necessary in conjunction with a filtering practice. Filters can help reduce detention requirements for a site by providing elongated flow paths, longer times of concentration, and volumetric losses from infiltration and evapotranspiration. While filters are not recommended to provide quantity controls, they can be used to treat the quality of runoff on the surface before it is discharged to an underground perforated pipe used for infiltration of peak discharges. Therefore, filtering areas should either be designed "off-line" using a flow diversion or be designed to safely pass large storm flows while still protecting the ponding area, mulch layer and any vegetation.

General Site Feasibility

- Sand and organic filtering systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with imperviousness less than 75% will require sedimentation pretreatment techniques.
- Drainage Area – 5 acres maximum recommended; 0.5 to 2 acres is preferred. For larger sites, multiple bioretention areas can be used to treat runoff provided

appropriate site grading is accurately direct flows to each facility.

- Space Required – Approximately 7-10% of the tributary impervious area is required for practice footprint; minimum 200 ft^2 area for small sites (10 feet x 20 feet)
- Site Slope – Sloped areas immediately adjacent to practice should be less than 20% but greater than 0.5 – 1% to promote positive flow towards the practice.
- Practice Slope – The slope of the practice surface should not exceed 1% to promote even distribution of flow throughout practice.
- Minimum Head – A minimum of 3 to 4 feet of elevation difference is needed at a site from the inflow to the outflow, when an underdrain is used.
- Minimum Depth to Water Table – A separation distance of 3 feet recommended between the bottom of the filter area and the elevation of the seasonally high water table if the practice is being used to also infiltrate water. If the practice is only providing filtration, the separation distance can be eliminated.
- Soils – No restrictions; engineered media required; underdrain is required where parent soils are classified as Hydrologic Soil Group (HSG) C or D.
- Soil Infiltration rate – In some cases, an on-site test within the proposed infiltration area is needed to establish the infiltration rate below the infiltration area. One test pit per 200 sf of filter bed is recommended.
- Groundwater Protection – Do not allow infiltration of runoff from stormwater hotspot into groundwater.
- Aesthetics – Filtering practice locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.

Three Basic Bioretention Designs

The basic bioretention design is modified to account for different levels of annual rainfall (AR) on the island, as shown in Table 3.10 below:

Table 3.10: Three Design Variants for Island Bioretention

DESIGN FACTOR	DESIGN NO. 1 (AR < 25 inches)	DESIGN NO. 2 (AR 26 - 74 inches)	DESIGN NO. 3 (AR > 75 inches)
Water Quality Volume	0.8 inch storm	1.0 inch storm	1.5 inch storm
Cells	Two	Two	Two
Pretreatment	25% of SA	35% of SA	50% of SA
Underdrain	Not required	Recommended	Required
Surface Cover	Washed limestone or pumice stone	Pumice	Organic mulch
Vegetation	A few planting holes	Trees 15’ o.c.	Native trees/shrubs

Irrigation	Only to planting holes	Short-term to establish growth	Not recommended
Infiltration	Yes, six inch rock sump below underdrain	Where soil testing indicates it is feasible	Where soil testing indicates it is feasible
Surface Overflow?	Elevated drop inlet above max ponding height	Yes, safely direct excess runoff to surface or SD pipe	Yes, safely direct excess runoff to surface or SD pipe
Depth of Media Filter	Min. 2 feet	Min. 3 feet	Min 4 feet
Connection to Underground Perforated Pipes	OK, after full surface WQ_v treatment in Bioretention area. No peak discharge credit given for water quality volume		

RO = Volumetric runoff
SA = Surface area of bioretention
oc = on center
SD = storm drain pipe
WQ_v = water quality volume

<u>Conveyance</u>

- If runoff is delivered by a storm drain pipe or is along the main conveyance system, the filtering practice shall be designed off-line, and a flow splitter or diversion structure should be provided to divert the WQ_v to the filtering practice and allow larger flows to bypass the system.
- Where a flow splitter is not used, contributing drainage areas should be limited to about 1.0 acre, and an overflow should be provided within the practice to pass a percentage of the WQ_v to a stabilized water course or storm drain.
- The overflow associated with the 10- or 25-year storm should be controlled so that velocities are non-erosive at the outlet point (i.e., prevent downstream slope erosion). Common overflow systems within the structure consist of a yard drain inlet, where the top of the yard drain inlet is placed at the elevation of the shallow ponding area.
- A stone drop of about six inches or small stilling basin should be provided at the inlet of bioretention areas where flow enters the practice through curb cuts.
- Bioretention areas with underdrains should be equipped with a minimum “4” underdrain diameter in a 1' gravel bed. The porous gravel bed prevents standing water in the system by promoting drainage. A very permeable filter fabric or graded stone matrix should be placed between the underdrain layer and the filter media.

Pretreatment

- Dry or wet pretreatment shall be provided prior to filter media equivalent to at least 25% of the computed WQ_v. The typical method is a sedimentation basin that has a length to width ratio of 1.5:1. Sedimentation basins shall have a minimum depth of 3.0 ft. The Camp-Hazen equation is used to compute the required surface area for sedimentation basins for sand and organic filters requiring pretreatment (WSDE, 1992) as follows:

$$A_s = (Qo/W) = \text{Ln}\ (1\text{-}E)$$

where:

A_s	=	Sedimentation basin surface area (ft^2)
E	=	sediment trap efficiency (use 90%)
W	=	particle settling velocity (ft/sec)
		use 0.0004 ft/sec for imperviousness
Qo	=	Discharge rate from basin = (WQ_v/24 hr)

Equation reduces to

$$A_s = (0.066)\ (WQ_v)\ ft^2$$

- Optional pretreatment cells for bioretention area will consist of a minimum one foot deep surface cell connected to bioretention area with an impermeable filter fabric on the bottom and a two-inch layer of sand or crushed rock. The cell shall be at least six inches higher in elevation than the main bioretention.
- Adequate pretreatment for bioretention systems should incorporate all of the following: (a) grass filter strip below a level spreader or grass channel, (b) washed limestone aggregate diaphragm and (c) a mulch layer.
- Bioretention should not be used to treat runoff from dirt parking lot or dirt roads due to a high potential for clogging from sediment.

Treatment

- Sand and organic filter beds typically have a minimum depth of 18". A minimum filter bed depth of 12" may be approved on a case-by-case basis as demonstrated by the designer that 18" is not feasible.
- The entire treatment system (including pretreatment) shall be sized to temporarily hold at least 75% of the WQ_v prior to filtration.
- The filter area for sand and organic filters should be sized based on the principles of Darcy's Law. A coefficient of permeability (k) should be used as follows:

Sand:	3.5 ft/day (City of Austin, 1988)
Peat:	2.0 ft/day (Galli, 1990)
Leaf compost:	8.7 ft/day (Claytor and Schueler, 1996)
Bioretention Soil:	1.0 ft/day for sandy-loam soils

The required filter bed area is computed using the following equation:

$$A_f = (WQ_v)\ (d_f)\ /\ [(k)\ (h_f + d_f)\ (t_f)]$$

Where:

A_f = Surface area of filter bed (ft^2)
d_f = Filter bed depth (ft)
k = Coefficient of permeability of filter media (ft/day)
h_f = Average height of water above filter bed (ft)
t_f = Design filter bed drain time (days)
(1.67 days or 40 hours is recommended maximum t_f for sand filters; 2 days for bioretention)

- Bioretention should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.
- Bioretention systems shall consist of the following treatment components: A minimum two foot deep planting soil bed (i.e., “filter bed”), a surface cover layer, and a 9 to 12 inch deep surface ponding area (see Table 3.10). A minimum 12” filter bed depth may be approved on a case-by-case basis as demonstrated by the designer that 24” is not feasible. In this case, extra organic matter must be added to the soil matrix.
- The filter bed shall be a made soil mixed on-site with the characteristics as shown in Table 3.11.
- Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth.

Table 3.11. Construction Specifications for Island Bioretention Areas

Pea Gravel/Limestone	Clean, double washed stone (#7 or #8)
Underdrain Gravel	3” min clean, double washed # 57 stone over underdrain; 3” addl of pea gravel/washed limestone on top for filter.
Underdrain Pipe	4” rigid schedule 40 PVC pipe, with 3/8” perforations @ 6” oc, each underdrain on 1% slope located 20 feet oc from next pipe
Soil Media	50% sand, 30% acceptable topsoil, 20% aged organic leaf compost derived on island.
Surface Cover	Layer of 1 to 3” pumice stone or crushed limestone, OR 2” layer of shredded tangantangan brush, coconut fronds or banana leaves, aged at least six months.
Bottom Geotextile	Bottom only. Non-woven polyprene geotextile w/ flow rate of > 110 gallons/minutes/square foot (e.g., Geotext 351 or equivalent).
Top Soil	Testing to ensure that it has loamy sand or sandy loam texture, with less than 5% clay content, corrected pH 6 to 7, and organic matter of at least 2%.
Trees*	12 feet oc, 1” minimum caliper
Shrubs*	8 feet oc
Ground Cover*	Buffalograss or kiligrass anchored in erosion control fabric.
Species selection dependent on design, drought tolerance and commercial availability	

Landscaping

- Sand and organic filters can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.
- A dense, healthy vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into the practice.
- Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan must be provided for bioretention areas.
- General planting recommendations for bioretention areas are as follows:
  - Native plant species should be specified over non-native species.
  - Vegetation for bioretention areas should be selected based on a specified zone of hydric tolerance. For example, *Design No. 1* should emphasize just a few trees or shrubs that can tolerate dry conditions (Xeriscapes), and will generally lack surface cover of turf or vegetation. *Design No. 2* also emphasizes a few planting holes for larger trees and shrubs. *Design No. 3* features trees, shrubs and groundcovers.
  - Woody vegetation should not be located at points of inflow.
  - Trees should not be planted directly overtop of underdrains and may be best located along the perimeter of the practice.
  - A tree density of approximately one tree per 300 square feet (i.e., 15 feet on-center) is recommended. Shrubs and herbaceous vegetation should generally be planted at higher densities (10 feet on-center and 5.0 feet on-center, respectively), if they can be sustained without supplemental irrigation.
- Filter areas do not pose any major safety hazards, and fencing is generally not needed or desirable.

Maintenance

Some general bioretention maintenance considerations are provided below, and a more detailed checklist of maintenance activities and associated timetables is provided in Table 3.12.

- Organic filters or sand filters that have a grass cover should be mowed a minimum of three times per growing season to maintain maximum grass heights less than 12 inches.
- A legally binding and enforceable maintenance agreement should be executed between the practice owner and the local review authority to ensure the following:
  - Sediment shall be cleaned out of the sedimentation chamber when it accumulates to a depth of more than 12 inches. Vegetation within the sedimentation chamber shall be limited to a height of 18 inches. The sediment chamber outlet devices shall be cleaned/repaired when drawdown times exceed 36 hours. Trash and debris shall be removed as necessary.

- Silt/sediment shall be removed from the filter bed when the accumulation exceeds one inch. When the filtering capacity of the filter diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), the top few inches of discolored material shall be removed and shall be replaced with fresh material. The removed sediments shall be disposed in an acceptable manner (i.e., landfill).

- Adequate access must be provided for all filtering facilities for inspection, maintenance, and landscaping upkeep.
- The surface of the ponding area may become clogged with fine sediment over time. Core aeration or cultivating of unvegetated areas may be required to ensure adequate filtration.
- All filtering areas must be covered by a drainage easement to allow inspection and maintenance. If filtering area is located in a residential area, the existence and purpose of the BMP shall be noted on the deed of record.
- The most frequently cited maintenance concern for filtering BMPs is surface and underdrain clogging caused by vegetation, organic matter, sediment, hydrocarbons, and algal matter. Common operational problems include:
  - standing water
  - clogged filter surface
  - broken observation wells
  - inlet, outlet or underdrains clogged
- Effective long-term operation of filtering practices requires dedicated and routine maintenance tasks performed on consistent timetable.

Table 3.12 Recommended Maintenance Activities for Bioretention Areas

Activity	Schedule
• Pruning and weeding to maintain appearance. • Mulch replacement when erosion is evident. • Remove trash and debris.	As needed
• Inspect inflow points for clogging (off-line systems). Remove any sediment from pretreatment cell. • Inspect trees and shrubs for survival and replace any dead or severely diseased vegetation.	Semi-annually
• Inspect and remove any sediment and debris build-up in pretreatment areas. • Inspect inflow points and bioretention surface for build up of sediments	Annually
• Replace mulch if used for surface cover area. • Replace pea gravel diaphragm or filter fabric if warranted. • The planting soils should be tested for pH to establish acidic levels. If the pH is below 5.2, limestone should be applied. If the pH is above 7.0 to 8.0, then iron sulfate plus sulfur can be added to reduce the pH.	2 to 3 years

Many design features can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include: limiting drainage area, providing easy site access, providing pretreatment, and utilizing native plantings.

The construction phase is another critical step where many maintenance problems can be minimized or avoided. The most important maintenance guideline to follow during construction is to make sure that the contributing drainage area has been fully stabilized prior to bringing the practice "on line."

Inspections during construction are needed to ensure that the filtering practice is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is acceptable to the professional designer.

3.4.2.4 Open Channel Systems

Open channel systems are vegetated open channels that are explicitly designed to capture and treat the full WQ_v within dry or wet cells formed by check dams or other means. Designs include:

- O-1 Dry Swale (Figure 3.12)
- O-2 Oversized Swale
- O-3 Amended Grass Channel

Oversized swales and amended grass channels are design variants of the dry swale.

Treatment Suitability: Open Channel Systems can meet water quality treatment goals only.

NOTE: Graphic adopted from CWP, 2002.

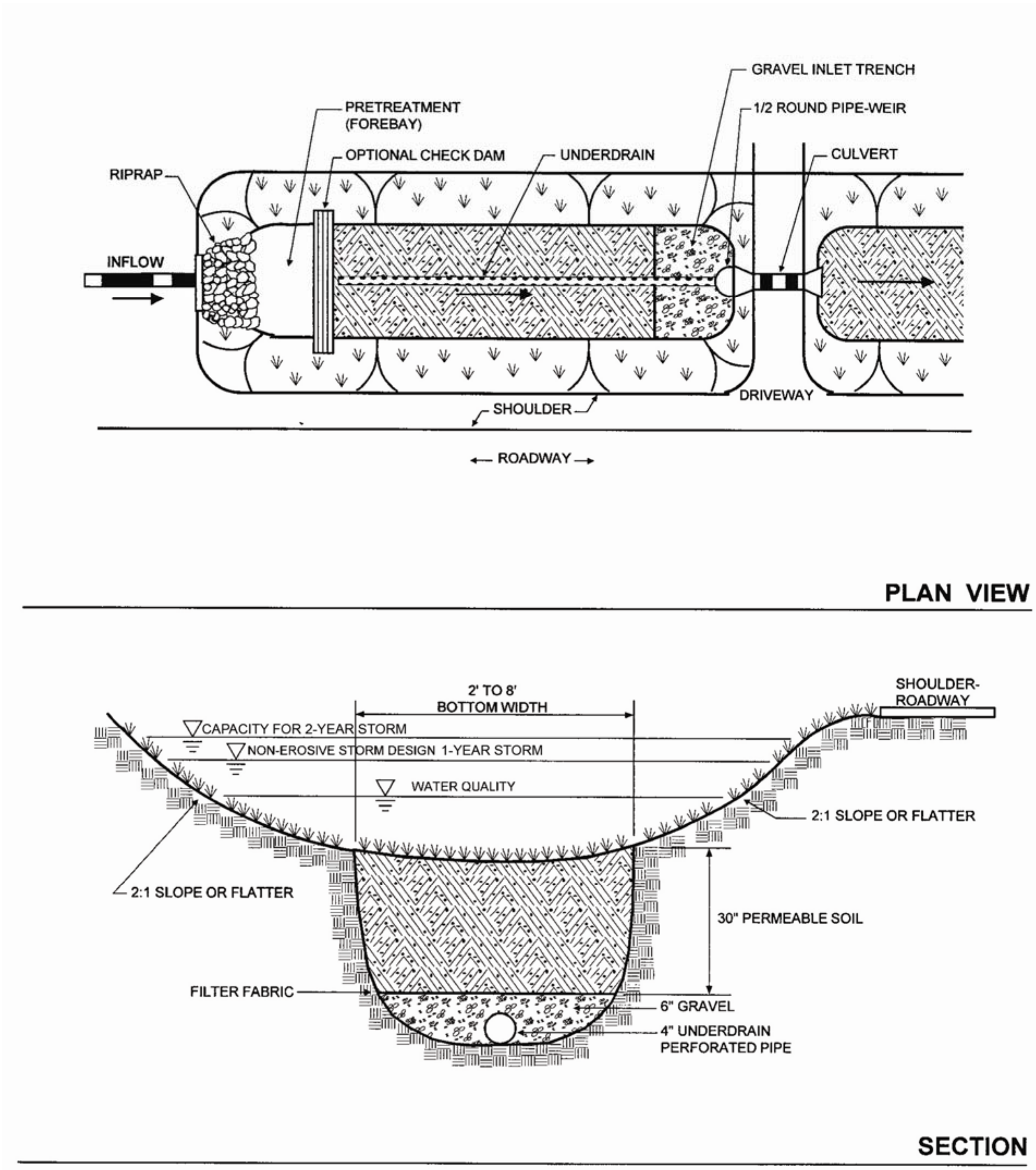


Figure 3.12 Dry Swale (O-1)

Island Adaptations

- Thin, nutrient poor soils with low water holding capacity make it difficult for dense vegetative cover to become established on new swales
- In leeward portions of the island where annual rainfall is low and ET rates are high, it may not be possible to maintain dense grass cover without supplemental irrigation, which is an unwise use of scarce freshwater resources.
- The contributing drainage areas to most swales will have exposed soils that are prone to erosion, so island swales need to be designed to accommodate a high sediment load.

General Description

Swales can be used either for pretreatment or as a stand alone water quality practice. All swale designs are generally located adjacent to paved surfaces and with stabilized drainage areas that have a slope less than 5%. Three kinds of swales can be used depending on amount of annual rainfall: oversized swales with check dams, amended grass channels and engineered dry swales (Table 3.13).

> *Dry swales* act as a filtering device, and contain 18 to 24 inches of filter media below the bottom of the swale, and an underdrain when underlying soils have an infiltration rate of less than 0.5 inches per hour.
>
> *Oversized swales* provide sediment trapping capacity above the surface of the swale, and may not be able to consistently maintain dense vegetative cover.
>
> *Amended grass channels* include a thin layer of topsoil, compost, sand, lime and erosion control fabric to create better start up conditions to establish dense grass cover. Depending on slope, amended grass swales may contain coir fiber log check dams to temporarily retain runoff, and enable greater infiltration.

All three swale designs are an excellent practice to remove pollutants through filtering and settling, evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption. Grass channels and dry swales can be designed to promote additional infiltration when parent soils have good permeabilities (i.e., infiltration rates > 1.0 in/hr).

Swales with greater than 5% slope should be designed following road construction guidelines for ESC control. This normally entails the use of water bars, cross drains, broad-based dips and sediment traps with defined storage capacity to prevent erosion.

Swales are suitable for most low density land uses, so long as they have limited contributing drainage (e.g., typically less than 5 acres) and meet acceptable slope conditions. Swales can be incorporated into landscaped areas. Swales generally cannot provide quantity controls but must be designed to safely pass large storm flows without eroding the swale. Swales can help reduce detention requirements at a site by elongating flow paths, increasing time of concentration, and reducing runoff volumes.

Table 3.13: Three Design Variants for Island Swales

<table>
<tr><th>DESIGN FACTOR</th><th>DESIGN NO. 1
(AR < 25 inches)</th><th>DESIGN NO. 2
(AR 26 - 74 inches)</th><th>DESIGN NO. 3
(AR > 75 inches)</th></tr>
<tr><td>Water Quality Volume</td><td>0.8 inch storm</td><td>1.0 inch storm</td><td>1.5 inch storm</td></tr>
<tr><td>Swale Design</td><td>Over-sized swales w/ check dams</td><td>Amended grass channels</td><td>Dry swales</td></tr>
<tr><td>Surface Cover</td><td>Dirt w/ sparse vegetative cover</td><td>Grass & ECF</td><td>Grass</td></tr>
<tr><td>Soil Media?</td><td>No</td><td>Yes, 3 inches</td><td>Yes, 18+ inches</td></tr>
<tr><td>Erosion Control Fabric?</td><td>No</td><td>Yes</td><td rowspan="2">When slope is more than 3%</td></tr>
<tr><td>Check Dams?</td><td>Yes</td><td>Depends on Slope and Infiltration Rate</td></tr>
<tr><td>Dugouts?</td><td>Yes</td><td>No</td><td>No</td></tr>
<tr><td>Infiltration Testing?</td><td>No</td><td>Yes</td><td>Yes</td></tr>
<tr><td>Soil Testing?</td><td>No</td><td>Yes</td><td>No</td></tr>
<tr><td>Underdrain?</td><td>No</td><td>No</td><td>Yes, if f_c< 1 inch/hr</td></tr>
</table>

General Feasibility for Swales

- Annual Rainfall: not recommended as primary BMP when AR is less than 25 inches
- Slope: All swales should have maximum slopes of 5% and minimum slopes of 0.5%.
- Drainage Area – 5 acres maximum recommended; 1 to 2 acres is preferred.
- Space Required – Function of available head at site
- Head: One foot minimum (grass channel) 3 feet minimum for dry swale
- Minimum Depth to Water Table – A separation distance of at least 2 feet is recommended between the bottom elevation of the swale and the seasonally high water table, unless swale is designed as a linear wetland.

General Design Criteria for all Swales

- The general shape of swales shall be parabolic or trapezoidal to provide maximum width for runoff to be filtered and infiltrated.

- Swales that have a grass cover should be mowed as needed during the growing season to maintain maximum grass heights less than 12 inches.
- In addition, flows within the swale associated with the 10-year, one-hour storm should be controlled so that velocities are non-erosive.
- Pretreatment for swales should consist of plunge pools where concentrated flows enter and with level spreaders where lateral flows enter.
- Swales should have gentle side slopes (no more than 3:1 horizontal: vertical).
- A dense and vigorous vegetative cover should be established over the contributing pervious drainage areas before runoff can be accepted into a grass channel or dry swale. Ground cover with the swale should be capable of withstanding frequent periods of inundation and drought.

Design Criteria for Oversized Swales with Check Dams

- These swales are primarily used in low rainfall areas of the island where it is difficult to maintain grass cover without supplemental irrigation. These designs utilize dugouts behind low check dams in the swale to provide the requisite WQ_v. It is strongly recommended that twice the normal WQ_v be provided to provide capacity for future sediment deposition.
- Check dams can be composed of stone, logs, lumber or coir fiber logs, and must be firmly anchored into the sideslopes to prevent outflanking. The designer should ensure the check dam will be stable during the design storm event
- The height of the check dam relative to the normal channel elevation should not exceed two feet.
- Each check dam should have a weephole or similar drainage feature so it can dewater after storms. Armoring may be needed behind the check dam to prevent erosion, and the check dam shall be designed to spread runoff evenly over the surface
- Dugouts up to two feet deep may be provided in front of the swale to provide additional water quality volume. Direct access should be possible to each dugout to remove trapped sediments.

Design Criteria for Amended Grass Swales

This design is intended for portions of the island with moderate annual rainfall, but difficult soil conditions to maintain a dense grass cover. The bottom of the swale is amended with several inches of soil media anchored by a decomposable erosion control fabric (ECF). The soil media consists of a combination of topsoil, compost and lime, and is adjusted based on soil analysis. Infiltration testing is needed to determine whether the WQv can be met through filtering and infiltration alone without providing surface storage. Table 3.14 presents a simple guide for making this decision for various combinations of swale slopes and measured soil infiltration rates.

- If check dams are needed, staked coir fiber logs or equivalent check dams need to be installed to attain the desired WQ_v.
- Erosion control fabrics should utilize natural and decomposable fabrics such as

shredded coconut fiber or coir, and be firmly anchored in place.

- Swale soils must be tested to determine the nature of the soil amendment. At a minimum, the soils should be tested for nutrient requirements, acidity, and water holding capacity. In addition at least one infiltration test should be conducted per every 100 feet of swale.
- Designers should adjust the dimensions of the swale (bottom width and slope) to achieve the greatest contact time.
- Designers should select the most appropriate warm season grass species suited for site conditions. CTHAR NM-4 provides a useful guide to Hawaii grasses with respect to drought and shade tolerance, nutrient requirements, and maintenance needs.

Table 3.14: Conditions where Check Dams (CD) are needed to get Surface WQ_v Storage

Infiltration Rate (in/hr)	**Swale Slope**				
	0.5 to 1%	**1 to 2 %**	**2 to 3%**	**3 to 4 %**	**4 to 5%**
0 to 0.5	CD	CD	CD	CD	CD
0.5 to 1.0		CD	CD	CD	CD
1.1 to 2.0			CD	CD	CD
2.0 to 4.0				CD	CD
4.1 or greater					CD

Design Criteria for Dry Swales

This design is for higher rainfall areas on the island. The dry swale contains a deeper bed of soil media that acts as filter, and may also have an underdrain enclosed in a gravel jacket if soil infiltration rates are less than one inch per hour. The basic design criteria for dry swales are outlined in Schueler and Claytor (1996). The following adaptations are recommended for Hawaii.

- The minimum depth of the soil media can be 18 inches, if soils are relatively permeable.
- The media should be the same composition as that used for bioretention areas.
- Check dams are only needed when slopes exceed 3%.

Conveyance

- The peak velocity for the 2-year storm must be non-erosive (i.e., 3.5-5.0 fps).
- Open channels shall be designed to safely convey the 10-year, 1-hour storm with a minimum of 6 inches of freeboard.
- The maximum allowable temporary ponding time within a channel shall be less than 48 hours. An underdrain system shall be used in the dry swale to ensure this ponding time.

- Channels shall be designed with moderate side slopes (flatter than 3:1) for most conditions. Designers may utilize a 2:1 maximum side slope, where 3:1 slopes are not feasible.
- Open channel systems which directly receive runoff from non-roadway impervious surfaces may have a 6-inch drop onto a protected shelf (washed, rounded limestone aggregate diaphragm) to minimize the clogging potential of the inlet. Runoff from roads shall drain over a vegetative slope prior to flowing into a swale.
- The underdrain system should be composed of a 6" limestone aggregate bed with a 4" PVC pipe.

<u>Pretreatment</u>

- Provide 10% of the WQ_v in pretreatment. This storage is usually obtained by providing check dams at pipe inlets and/or driveway crossings. Road drainage entering a swale along the length of the road may pre-treat runoff using a vegetative filter strip. An effective filter strip shall be no steeper than 6% slope and 4 feet wide for each travel lane draining to the swale.
- Utilize a washed, rounded limestone aggregate diaphragm and gentle side slopes along the top of channels to provide pretreatment for lateral sheet flows.

<u>Treatment</u>

- Temporarily store the WQ_v within the facility to be released over a minimum 30-minute duration.
- Design with a bottom width no greater than 8 feet to avoid potential gullying and channel braiding, but no less than two feet.
- Open channels should maintain a maximum ponding depth of one foot at the mid-point of the channel, and a maximum depth of 18" at the end point of the channel (for storage of the WQ_v).

<u>Landscaping</u>

- Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel. (See Section 3.6 for landscaping guidance for Hawaii).

<u>Maintenance</u>

- A legally binding and enforceable maintenance agreement shall be executed between the facility owner and the local review authority to ensure the following:
  - Sediment build-up within the bottom of the channel or filter strip is removed when 25% of the original WQ_v volume has been exceeded.
  - Vegetation in dry swales is mowed as required to maintain grass heights in the 4 to 6 inches range, with mandatory mowing once grass heights exceed 10”.

In general, the oversized swales with check dams will tend to have the greatest maintenance burden since sediments will need to regularly be cleaned out. Effective long-term operation of swales requires routine maintenance performed on a defined timetable. Some important maintenance considerations are provided in Table 3.15.

Table 3.15 Recommended Maintenance Activities for Swales

Activity	Schedule
• If swale is clogged or partially clogged, manual manipulation of the surface layer of sand may be required. Remove the top few inches of media, roto-till or otherwise cultivate the surface, and replace media with like material meeting the design specifications. • Initial irrigation may be needed to establish grass cover.	As needed
• Ensure the swale is clear of debris. • Mow the swale at least four times a year • Check to ensure that the filter surface is not clogging (also check after storms greater than about 1").	Monthly
• Check to see that the dugouts, check dams and swale are clean of sediment and remove as necessary. • Inspect check dams to ensure good condition and no evidence of erosion. • Re-seed bare patches. • Stabilize any eroded areas. • Ensure that flow is not bypassing the swale.	Annually

The construction phase is another critical step where maintenance problems can be minimized or avoided. As with other practices, the most critical construction requirement is to ensuring the contributing drainage area has been fully stabilized prior to bringing the swale "on line". Inspections during construction are needed to ensure the swale is installed in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to verify the contractor's interpretation of the plan is acceptable with the designer.

3.5 Selecting the Most Effective Stormwater Treatment System

The selection of appropriate stormwater practices for any given site involves a combination of the process of elimination and the process of addition. Typically, no single practice will meet all stormwater management objectives. Instead, a series of practices are generally required. Certain practices can be eliminated from consideration based on one limiting factor. But several practices may ultimately "survive" the elimination process. The most appropriate practices are those that are both feasible, cost effective, and achieve the maximum benefits for watershed protection.

Structural stormwater practices are frequently designed to meet either *water quality* and/or *water quantity* control requirements. *Water quality* facilities are typically applied to control and treat pollutants that wash off urban land surfaces and are designed for a prescribed volume of runoff, which is usually relatively small and is called the water quality volume (WQ_v), as described in Section 3.3.3. *Water quantity* facilities are typically designed to control increases in peak flow rates and volumes associated with larger storms typically of the 10-year frequency, 1-hour storm up to the 100-year storm, depending on site location and drainage area.

This section presents a series of matrices that can be used as a screening process for selecting the best BMP or group of BMPs for a development site. It also provides guidance for locating practices on the site. The matrices presented can be used to screen practices in a step-wise fashion. Screening factors include:

- Land Use
- Physical Feasibility
- Watershed
- Stormwater Management Capability
- Pollutant Removal
- Community and Environmental

The six matrices presented here are not exhaustive. Specific additional criteria may be incorporated depending on local design knowledge and resource protection goals. Caveats for the application of each matrix are included in the detailed description of each.

More detail on the proposed step-wise screening process is provided below:

Step 1 Land Use
Which practices are best suited for the proposed land use at this site? In this step, the designer makes an initial screen to select practices that are best suited to a particular land use or to exclude those practices that are ill suited for certain land uses. For example, infiltration practices should not be utilized where runoff is expected to contain high levels of dissolved constituents, such as metals or hydrocarbons or where prior subsurface contamination is evident. Increased hydraulic loading to contaminated soils can accelerate pollutant migration and/or leaching into underlying groundwater.

Step 2 Physical Feasibility
Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP? In this step, the designer screens the BMP list using Matrix No. 2 to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site might limit the use of a BMP. For example, stormwater ponds/wetlands generally require a drainage area approaching 25 acres unless groundwater interception is likely, and can consume a significant land area.

Step 3 Watershed

What watershed protection goals need to be met in the resource my site drains to? Matrix No.3 outlines BMP goals and restrictions based on the resource being protected. This set of factors involves screening out those practices that might contradict overall watershed protection strategies, or eliminating management requirements where they are unnecessary or inappropriate. For example, practices that maximize pollutant and toxicity reduction are typically relevant in urban watersheds and water *quantity controls* are not necessary for discharges to tidal waters or large river systems. Regulatory requirements under the Clean Water Act, Total Maximum Daily Load (TMDL) reduction requirements and/or interests from watershed associations may dictate the type, location, and design requirements for stormwater management practices.

Step 4 Stormwater Management Capability

Can one BMP meet all design criteria, or is a combination of practices needed? In this step, designers can screen the BMP list using Matrix No. 4 to determine if a particular BMP can manage a wide range of storm frequencies. For example, the filtering practices are generally limited to water quality treatment and seldom can be utilized to meet larger stormwater management objectives. At the end of this step, the designer can screen the BMP options down to a manageable number and determine if a single BMP or a group of BMPs are needed to meet stormwater sizing criteria at the site.

Step 5 Pollutant Removal

How do each of the BMP options compare in terms of pollutant removal? In this step, the designer views removal of select pollutants to determine the best BMP options for water quality. Some practices have a better pollutant removal potential than others or have a better capability to remove certain pollutants. For example, stormwater ponds/wetlands provide excellent total suspended solids (TSS) removal but only modest total nitrogen (TN) removal.

Step 6 Community and Environmental

Do the remaining BMPs have any important community or environmental benefits or drawbacks that might influence the selection process? In this step, a matrix is used to compare the BMP options with regard to maintenance, habitat, community acceptance, cost and other environmental factors. Some practices can have significant secondary environmental impacts that might preclude their use in certain situations. Likewise, some practices have frequent maintenance and operation requirements that are beyond the capabilities of the owner. For example, infiltration practices are generally considered to have the highest maintenance burden because of a high failure history and consequently, a higher pre-treatment maintenance burden and/or replacement burden. Infiltration practices should not be used where prior subsurface contamination is present due to the increased threat of pollutant migration associated with increase hydraulic loading from infiltration systems.

3.5.1 Step 1 - Land Use

This matrix allows the designer to make an initial screen of practices most appropriate for a given land use.

Rural. This column identifies BMPs that are best suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre).

Residential. This column identifies the best treatment options in medium to high density residential developments.

Roads and Highways. This column identifies the best practices to treat runoff from major roadway and highway systems.

Commercial Development. This column identifies practices that are suitable for new commercial development.

Hotspot Land Uses. This column examines the capability of BMPs to treat runoff from designated hotspots. BMPs that receive hotspot runoff may have design restrictions, as noted.

Ultra-Urban Sites. This column identifies BMPs that work well in the ultra-urban environment, where space is limited and original soils have been disturbed. These BMPs are frequently used at redevelopment and infill sites.

Table 3.16 BMP Selection Matrix 1-Land Use

BMP Group	BMP Design	Rural	Residential	Roads and Highways	Commercial/ High Density	Hotspots	Ultra Urban
Pond/ Wetland	Micropool ED	○	○	○	◗	①	●
	ED Wetland	○	○	◗	◗	①	●
	Wet ED Pond	○	○	○	◗	①	●
Infiltration	Infiltration Trench/Chambers	◗	◗	○	○	●	◗
Filters	Sand Filter	●	●	◗	○	②	○
	Organic Filter	●	◗	○	○	②	○
	Bioretention	◗	◗	○	○	②	○
Open Channels	Dry Swale	○	◗	○	◗	②	◗
	Oversized Swale	○	◗	○	◗	②	◗
	Amended Grass Channel	○	◗	○	◗	②	◗

○: Yes. Good option in most cases.
◗: Depends. Suitable under certain conditions, or may be used to treat a portion of the site.
●: No. Seldom or never suitable.
①: Acceptable option, but may require a pond liner to reduce risk of groundwater contamination.
②: Acceptable option, if not designed as an exfilter. (An exfilter is a conventional stormwater filter without an underdrain system. The filtered volume ultimately infiltrates into the underlying soils.)

3.5.2 Step 2 - Physical Feasibility

This matrix allows the designer to evaluate possible options based on physical conditions at the site. More detailed testing protocols are often needed to confirm physical conditions at the site. Five primary factors are:

Soils. The key evaluation factors are based on an initial investigation of the NRCS hydrologic soil groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors.

Water Table. This column indicates the minimum depth to the seasonally high water table from the bottom elevation, or floor, of a BMP.

Drainage Area. This column indicates the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (baseflow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope guidance refers to how flat the area where the practice is installed must be and/or how steep the contributing drainage area or flow length can be.

Head. This column provides an estimate of the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

Table 3.17 BMP Selection Matrix 2-Physical Feasibility

BMP Group	BMP Design	Soils	Water Table	Drainage Area (Ac)	Site Slope	Head (Ft)
Pond	Micropool ED	Limestone and HSG A soils require pond liner	3 foot* separation if hotspot or aquifer	10 min**	No more than 20%	3 to 10 ft
	ED/Shallow Wetland			25 min**		
	Wet ED Pond					
Infiltration	Infiltration Trench/Chamber	f_c > 0.5* inch/hr	3 feet*	5 max	No more than 20%	1 ft
Filters	Sand Filter	OK	2 feet	10 max ***	no more than 20%	2 to 7 ft
	Organic Filter			5 max***		2 to 4 ft
	Bioretention	Made Soil				5 ft
Open Channels	Dry Swale	Made Soil	2 feet	5 max	No more than 5%	3 to 5 ft
	Oversized Swale	Made Soil	2 feet	5 max		1 ft
	Amended Grass Channel	Made Soil	2 feet	5 max		1 ft

Notes: OK= not restricted, WT= water table, PT = pretreatment, f_c =soil permeability

* denotes a required limit, other elements are planning level guidance and may vary somewhat depending on site conditions or design variants.

** unless adequate water balance and anti-clogging device installed

***drainage area can be larger in some instances.

3.5.3 Step 3 - Watershed

The design and implementation of stormwater management control measures is strongly influenced by the nature and sensitivity of the receiving waters. In some cases higher pollutant removal, more recharge or other environmental performance is warranted to fully protect the resource quality, human health and/or safety. Based on the discussions in Section 3.1, critical resource areas include: *groundwater, freshwater streams, ponds, wetlands, and coastal waters.* Table 3.18 presents the key design variables and considerations that must be addressed for sites that drain to any of the above critical resource areas.

Table 3.18 BMP Selection Matrix 3-Watershed

BMP Group	**Critical Resource Area Specific Criteria**				
	Groundwater	Freshwater Streams	Freshwater Ponds	Freshwater Wetlands	Coastal Waters
Ponds/Wetlands	Pre-treat hotspots. Provide 2' SD from seasonal high groundwater elevation Pretreat hotspots at 100% of WQ_v.	OK, quantity control required.	Design for enhanced TP removal. Use ponds with wetlands for better TP removal.	Design for enhanced TP removal. Use ponds with wetlands for better TP removal.	Moderate bacteria removal. Good to moderate TN removal. Provide permanent pools.
Infiltration	100' SD from water supply wells.	OK, but soils overlaying volcanic dominated regions may limit application.	OK, if site has appropriate soils.	OK, if site has appropriate soils.	OK, but maintain 3' SD from seasonal high groundwater. Best TN removal within B soil horizon.
Filtering Systems	OK, ideal practice for pretreatment prior to infiltration.	Practices rarely provide quantity control, other BMP needed.	OK, moderate to high TP removal.	OK, moderate to high TP removal.	OK, moderate to high bacteria and nitrogen removal.
Open Channels	OK, pre-treat 100% WQ_v for hotspots.	OK, should be linked w/ basin for quantity control.	OK, Dry swale provides the best TP removal.	OK, Dry swale provides the best TP removal.	Poor bacteria removal.

SD = separation distance
ED = extended detention

3.5.4 Step 4 - Stormwater Management Capability

This matrix examines the capability of each BMP option to meet stormwater management goals. It shows whether a BMP can provide for:

Water Quality Criteria. The matrix tells whether each practice can be used to provide water quality treatment effectively. For more detail, consult the pollutant removal matrix, Matrix 5.

Recharge. The matrix indicates whether each practice can provide groundwater recharge. Groundwater recharge is not a formal criteria but often a design goal to help replenish groundwater supplies for drinking water and to augment freshwater stream flows.

Quantity Control. The matrix shows whether a BMP can typically meet flooding issues for the site. Again, the finding that a particular BMP cannot meet these requirements does not necessarily mean that it should be eliminated from consideration, but rather is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream stormwater pond).

Table 3.19 BMP Selection Matrix 4-Stormwater Management Capability

BMP Group	BMP Design	Water Quality?	Recharge?	Quantity Control?
Ponds/ Wetlands	Micropool ED	○	●	○
	ED Wetland	○	●	○
	Wet ED Pond	○	●	○
Infiltration	Infiltration Trench/Chambers	○	○	❹
Filters	Sand Filter	○	❷	●
	Organic Filter	○	❷	●
	Bioretention	○	❷	●
Open Channels	Dry Swale	○	❷	●
	Oversized Swale	○	❷	●
	Amended Grass Channel	❸	❷	●

○ Practice generally meets this stormwater management goal.
● Practice can almost never be used to meet this goal.
❶ Since intercepting groundwater, side slopes contribute.
❷ Provides recharge only if designed as an exfilter system.
❸ Practice may partially meet this goal, or under specific site and design conditions.
❹ Can be used to meet flood control in rare conditions, with very cobbly or highly permeable soils.

3.5.5 Step 5 - Pollutant Removal

This matrix examines the capability of each BMP option to remove specific pollutants from stormwater runoff. The matrix includes data for:

- Total Suspended Solids
- Total Phosphorous
- Total Nitrogen
- Metals
- Bacteria
- Hydrocarbons

Table 3.20 BMP Selection Matrix 5-Pollutant Removal

Practice	TSS [%]	TP [%]	TN [%]	Metals[1] [%]	Bacteria [%]	Hydrocarbons [%]
Wet Ponds/Wetlands	80	51	33	62	70	81[2]
Filtering Practices	86	59	38	69	37[2]	84[2]
Infiltration Practices[3]	95[2]	80	51	99[2]	N/A[5]	N/A
Open Channels[4]	81	34	84[2]	70	N/A	62[2]

1. Average of zinc and copper. Only zinc for infiltration.
2. Based on fewer than five data points (i.e., independent monitoring studies).
3. Includes porous pavement, which is not on the list of approved practices for Hawaii.
4. Higher removal rates expected for dry swales.
5. While no data is available on the removal of bacteria for infiltration practices, it is generally accepted that if there is a good soil matrix, removal is expected to be high; while if there is little organic matter and a shallow soil profile over limestone, removal is likely to be poor.

N/A: Data not available

Removals represent median values from Winer (2000)

3.5.6 Step 6 - Community and Environmental

The last step assesses community and environmental factors involved in BMP selection. This matrix employs a comparative index approach. An open circle indicates that the BMP has a high benefit and a dark circle indicates that the particular BMP has a low benefit.

Maintenance. This column assesses the relative maintenance effort needed for an BMP, in terms of three criteria: frequency of scheduled maintenance, chronic maintenance problems (such as clogging) and reported failure rates. It should be noted that all BMPs require routine inspection and maintenance.

Affordability. The BMPs are ranked according to their relative construction cost per impervious acre treated. These costs exclude design, land acquisition, and other costs.

Community Acceptance. This column assesses community acceptance, as measured by three factors: market and preference surveys, reported nuisance problems, and visual orientation (i.e., is it prominently located or is it in a discrete underground location). It should be noted that a low rank can often be improved by a better landscaping plan.

Safety. A comparative index that expresses the relative public safety of an BMP. An open circle indicates a reasonably safe BMP, while a darkened circle indicates deep pools may create potential public safety risks. The safety factor is included at this stage of the screening process because liability and safety are of paramount concern in many residential settings.

Habitat. BMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features and vegetative cover of the BMP and its buffer.

Table 3.21 BMP Selection Matrix 6-Community and Environmental

BMP Group	BMP List	Ease Of Maintenance	Affordability	Community Acceptance	Safety	Habitat
Ponds/ Wetlands	Micropool ED	◗	○	◗	◗	◗
	ED Wetland	◗	◗	◗	◗	○
	Wet ED Pond	○	○	○	●	○
Infiltration	Infiltration Trench/Chambers	●	◗	○	○	●
Filters	Sand Filter	●	●	◗	○	●
	Organic Filter	◗	●	○	○	●
	Bioretention	◗	◗	◗	○	◗
Open Channels	Dry Swale	◗	◗	○	○	●
	Oversized Swale	◗	◗	○	○	●
	Amended Grass Channel	◗	◗	○	○	●

○ **High** ◗ **Medium** ● **Low**

3.6 General Landscaping for all BMPS

Landscaping is a critical element to improve both the function and appearance of stormwater best management practices (BMPs). This chapter provides landscaping criteria and plant selection guidance for effective stormwater BMPs. It is organized as follows:

The first section, 3.6.1, outlines general guidance that should be considered when landscaping any stormwater practice, as well as a detailed plant list of native woody and herbaceous species that can be used when preparing a stormwater planting plan. These practices include:

- Stormwater ponds and wetlands
- Infiltration and sand filter practices
- Bioretention
- Open Channels
- Filter Strips and Buffers

In addition, specific guidelines are presented for landscaping bioretention areas.

In Section 3.6.2, key factors in selecting plant material for stormwater landscaping are reviewed, including hardiness zones, physiographic regions, hydrologic zones, and cultural factors.

Native Species

This workbook encourages the use of native plants in stormwater management facilities. Native plants are defined as those species which evolved naturally to live in this region of the world. Practically speaking, this refers to those species which lived on the islands before recent human settlement. Many introduced species were weeds brought in by accident; others were intentionally introduced and cultivated for use as food, medicinal herbs, spices, dyes, fiber plants, and ornamentals.

Introduced species can often escape cultivation and begin reproducing in the wild. This is significant ecologically because many introduced species out-compete indigenous species and begin to replace them in the wild. Some introduced species are invasive, have few predators, and can take over naturally occurring species at an alarming rate. By planting native species in stormwater management facilities, we can help protect the natural heritage of Hawaii and provide a legacy for future generations.

Native species also have distinct genetic advantages over non-native species for planting in Hawaii. Because they have evolved to live here naturally, indigenous plants are best suited for the local climate. This translates into greater survivorship when planted and less replacement and maintenance during the life of a stormwater management facility. Both of these attributes provide cost savings for the facility owner.

Finally, people often plant exotic species for their ornamental value. While it is important to have aesthetic stormwater management facilities for public acceptance and the maintenance of property value, it is not necessary to introduce foreign species for this purpose. Many native species are aesthetically pleasing and can be used as ornamentals. When selecting ornamentals for stormwater management facilities, planting preference should be given to native ornamentals.

3.6.1 General Landscaping Guidance for All Stormwater BMPs

- Do not plant trees and shrubs within 15 feet of the toe of slope of a dam.
- Do not plant trees or shrubs known to have long tap roots within the vicinity of the earth dam or subsurface drainage facilities.
- Do not plant trees and shrubs within 15 feet of perforated pipes.
- Do not plant trees and shrubs within 25 feet of a hydraulic outlet control structure.
- Provide 15-foot clearance from a non-clogging, low-flow orifice.
- Herbaceous embankment plantings should be limited to 10 inches in height, to allow visibility for the inspector who is looking for burrowing rodents that may compromise the integrity of the embankment.
- Provide slope stabilization methods for slopes steeper than 2:1, such as planted erosion control mats. Also, use seed mixes with quick germination rates in this area. Augment temporary seeding measures with container crowns or root mats of more permanent plant material.
- Utilize erosion control mats and fabrics to protect in channels that are subject to frequent wash outs.
- Stabilize all water overflows with plant material that can withstand strong current flows. Root material should be fibrous and substantial but lacking a tap root.
- Sod drainage channels subjected to high velocities that are not stabilized by erosion control mats.
- Divert flows temporarily from seeded areas until stabilized.
- Check water tolerances of existing plant materials prior to inundation of area.
- Stabilize aquatic and safety benches with emergent wetland plants and wetland seed mixes.
- Do not block maintenance access to structures with trees or shrubs.
- Avoid plantings that will require routine or intensive chemical applications (i.e. turf area).
- Have soil tested to determine if there is a need for amendments.
- Select plants that can thrive with on-site soil with no additional amendments or a minimum of amendments.
- Decrease the areas where turf is used. Use low-maintenance ground cover to absorb run-off.
- Plant stream and edge of water buffers with trees, shrubs, ornamental grasses, and herbaceous materials where possible, to stabilize banks and provide shade.
- Maintain and frame desirable views. Be careful not to block views at entrances, exits, or difficult road curves. Screen or buffer unattractive views into the site.
- Use plants to prohibit pedestrian access to pools or steeper slopes that may be unsafe.

- The designer should carefully consider the long-term vegetation management strategy for the BMP, keeping in mind the "maintenance" legacy for the future owners. Keep maintenance area open to allow future access for pond maintenance. Provide a planting surface that can withstand the compaction of vehicles using maintenance access roads. Make sure the facility maintenance agreement includes a maintenance requirement of designed plant material.
- Provide Signage for:
    - Stormwater Management Areas to help educate the public when possible.
    - Wildflower/native grass areas, when possible, to designate limits of mowing.
- Avoid the overuse of any plant materials.
- Preserve existing natural vegetation when possible.

It is often necessary to test the soil in which you are about to plant in order to determine the following:

- pH; whether acid, neutral, or alkali
- major soil nutrients; Nitrogen, Phosphorus, Potassium
- minerals; such as chelated iron, lime

Have soil samples analyzed by experienced and qualified individuals, such as those at the Pacific Basin Natural Resources Conservation Service (NRCS), who will explain in writing the results, what they mean, as well as what soil amendments would be required. Certain soil conditions, such as marine clays or volcanic soils, can present serious constraints to the growth of plant materials and may require the involvement of qualified professionals. When poor soils can't be amended, seed mixes and plant material must be selected to establish ground cover as quickly as possible.

Areas that have recently been involved in construction can become compacted so that plant roots cannot penetrate the soil. Seeds lie on the surface of compacted soils, allowing seeds to be washed away or be eaten by birds. Soils should be loosened to a minimum depth of two inches, preferably to a four-inch depth. Hard soils may require discing to a deeper depth. The soil should be loosened regardless of the ground cover. This will improve seed contact with the soil, providing greater germination rates, allowing the roots to penetrate into the soil. If the area is to be sodded, discing will allow the roots to penetrate into the soil. Weak or patchy crops can be prevented by providing good growing conditions.

Whenever possible, topsoil should be spread to a depth of four inches (two-inch minimum) over the entire area to be planted. This provides organic matter and important nutrients for the plant material. This also allows the stabilizing materials to become established faster, while the roots are able to penetrate deeper and stabilize the soil, making it less likely that the plants will wash out during a heavy storm.

If topsoil has been stockpiled in deep mounds for a long period of time, it is desirable to test the soil for pH as well as microbial activity. If the microbial activity has been destroyed, it is necessary to inoculate the soil after application.

Remember that newly installed plant material requires water in order to recover from the shock of being transplanted. Be sure that some source of water is provided, should dry periods occur after the initial planting. This will reduce plant loss and provide the new plant materials with a chance to establish root growth.

Bioretention - Planting Soil Bed Characteristics

The characteristics of the soil for the bioretention facility are perhaps as important as the facility location, size, and treatment volume. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground.

The planting soil should be a sandy loam, loamy sand, loam (USDA), or a loam/sand mix (should contain ~80% sand, by volume). The clay content for these soils should by less than 5% by volume. Soils should fall within the SM, or ML classifications of the Unified Soil Classification System (USCS). A permeability of at least 1.0 feet per day (0.5"/hr) is required. The soil should be free of stones, stumps, roots, other woody material over 1" in diameter, or brush/seeds from noxious weeds. Placement of the planting soil should be in lifts of 12 to 18", loosely compacted (tamped lightly with a dozer or backhoe bucket). The specific characteristics are presented in Table 3.22.

Table 3.22 Planting Soil Characteristics (Adapted from EQR, 1996; ETAB, 1993)

Parameter	Value
PH range	5.2 to 7.00
Organic matter	1.5 to 4.0%
Magnesium	35 lbs. per acre, minimum
Phosphorus (P_2O_5)	75 lbs. per acre, minimum
Potassium (K_2O)	85 lbs. per acre, minimum
Soluble salts	. 500 ppm
Clay*	0 to 5%
Silt*	<15 to 20%
Sand*	>50%

*Native soil characteristics. Augment native soils with aged leaf compost and acceptable topsoil (see Section 3.4.2.3).

Mulch Layer

The mulch layer plays an important role in the performance of the bioretention system (surface layer varies based on design numbers 1-3). The mulch layer helps maintain soil moisture and avoids surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the mulch/soil interface. Mulch also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment.

The mulch for Bioretention Design No. 3 should be standard landscape style, single or double, shredded tangantangan or coconut mulch or chips. The mulch layer should be well aged (stockpiled or stored for at least six (6) months), uniform in color, and free of other materials, such as weed seeds, soil, roots, etc. The mulch should be applied to a maximum depth of three inches. Grass clippings should not be used as a mulch material.

Planting Plan Guidance

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat stormwater runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention facility (Figure 3.13). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions.

The layout of plant material should be flexible, but should follow the general principals described in Table 3.23. Tree density of approximately one tree per 300 square feet (i.e., 15 feet on center) is recommended. Shrubs and herbaceous vegetation should generally be planted at higher densities (10 feet on center and 5 feet on center, respectively). The objective is to have a system which resembles a random and natural plant layout, while maintaining optimal conditions for plant establishment and growth.

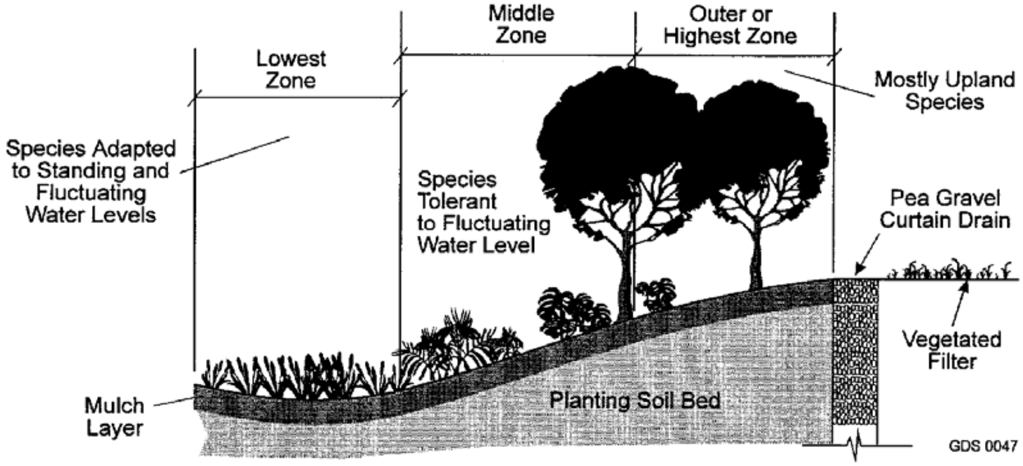


Figure 3.13 Planting Zones for Bioretention Facilities

Table 3.23 Planting Plan Design Considerations

Native plant species should be specified over exotic or foreign species.
Appropriate vegetation should be selected based on the zone of hydric tolerance
Species layout should generally be random and natural.
A canopy should be established with an understory of shrubs and herbaceous materials.
Woody vegetation should not be specified in the vicinity of inflow locations.
Trees should be planted primarily along the perimeter of the bioretention area.
Urban stressors (e.g., wind, sun, exposure, insect and disease infestation, drought) should be considered when laying out the planting plan.
Noxious weeds should not be specified.
Aesthetics and visual characteristics should be a prime consideration.
Traffic and safety issues must be considered.
Existing and proposed utilities must be identified and considered.

Plant Material Guidance

Plant materials should conform to the American Standard Nursery Stock, published by the American Association of Nurserymen, and should be selected from certified, reputable nurseries. Planting specifications should be prepared by the designer and should include a sequence of construction, a description of the contractor's responsibilities, a planting schedule and installation specifications, initial maintenance, and a warranty period and expectations of plant survival. Table 3.24 presents some typical issues for planting specifications.

Table 3.24 Planting Specification Issues for Bioretention Areas

Specification Element	Elements
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation through site clean-up.
Contractor's Responsibilities	Specify the contractor's responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B, bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency (annual mulching is most common); removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering schedule after initial installation (once per day for 14 days is common); repair/replacement of staking and wires.
Warranty	Specify the warranty period, required survival rate, and expected condition of plant species at end of warranty period.

3.6.2 Other Considerations in Stormwater BMP Landscaping

Use or Function

In selecting plants, consider their desired function in the landscape. Is the plant needed as ground cover, soil stabilizer, or a source of shade? Will the plant be placed to frame a view, create focus, or provide an accent? Does the adjacent use provide conflicts or potential problems and require a barrier, screen, or buffer? Nearly every plant and plant location should be provided to serve some function in addition to any aesthetic appeal.

Plant Characteristics

Certain plant characteristics are so obvious that they may actually be overlooked in the plant selection. These are:

- Size
- Shape

For example, tree limbs, after several years, can grow into power lines. A wide-growing shrub may block an important line of sight to oncoming vehicular traffic. A small tree could strategically block the view from a second-story window. Consider how these characteristics can work for you or against you, today and in the future.

Other plant characteristics must be considered to determine whether the plant will fit with the landscape today and through the years to come. Some of these characteristics are:

- Color
- Texture
- Aesthetic Interest, i.e.- Flowers, Fruit, Leaves, Stems/Bark
- Growth rate

In urban or suburban settings, residents living next to a stormwater system may desire that the facility be appealing or interesting. Aesthetics is an important factor to consider in the design of these systems. Failure to consider the aesthetic appeal of a facility to the surrounding residents may result in reduced value to nearby lots. Careful attention to the design and planting of a facility can result in maintained or increased values of a property.

Availability and Cost

Often overlooked in plant selection is the availability from wholesalers and the cost of the plant material. There are many plants listed in landscape books that are not readily available from the nurseries. Without knowledge of what is available, time spent researching and finding the one plant that meets all the needs will be wasted, if it is not available from the growers. It may require shipping, therefore, making it more costly than the budget may allow. Some planting requirements may require a special effort to find the specific plant that fulfills the needs of the site and the function of the plant in the landscape.

3.7 Case Studies

This section provides two case studies to illustrate the techniques presented in this Chapter. The first case study steps through the BMP selection process for a commercial site on Maui. The second case study shows how to determine the required treatment volume for a residential development on Kauai.

3.7.1 BMP Selection Example

The Honu Beach Shopping Center is a hypothetical commercial development located in Kihei, Maui. The 5-acre shopping center consists of many different businesses, which ultimately connect to an existing storm drain discharging to a nearby coastal area. Instead of trying to direct all the runoff from the site to one treatment facility, it is more effective to divide the area into subcatchments based on localized topography/grading and use. This example focuses on a bank, with a site area of 0.5 acres and 80% impervious cover (see Figure 3.14), with fill soils classified as "Urban Land" and 10 feet to groundwater. Using the site characteristics and the BMP selection matrices from Section 3.5, we will choose appropriate BMP(s) for this area.

BMP Selection Process

In order to select a treatment BMP for this site, we need to consider site constraints based on the categories presented in Section 3.5, as follows:

- Land Use
- Physical Feasibility
- Watershed
- Stormwater Management Capability
- Pollutant Removal
- Community and Environmental

Land Use: The site consists of mostly a parking lot and the building, with a few scattered landscaped areas. It is a commercial land use, but not a hotspot. Based on the Selection Matrix 1, the best BMPs are infiltration or filtering practices.

Physical Feasibility: The small area of our site is a physical constraint – there is not enough room to have a stormwater pond or wetland. The fill soils are fine for filtering and open channel practices.

Watershed: Our site discharges ultimately to coastal waters, for which the best practices are infiltration and filtering BMPs.

Stormwater Management Capability: All the BMPs are appropriate for treating the water quality volume – no constraints for this category.

Pollutant Removal: The main pollutant of concern for a parking lot is sediment and hydrocarbons from cars. The best practices for both of these are filtering practices.

Community and Environmental: From the previous matrices, we know that filtering practices are the best fit for our site. Using BMP Selection Matrix 6, bioretention systems are the most affordable of the filtering practices. In addition, bioretention areas can be planted with aesthetically pleasing plants and have low public safety risks.

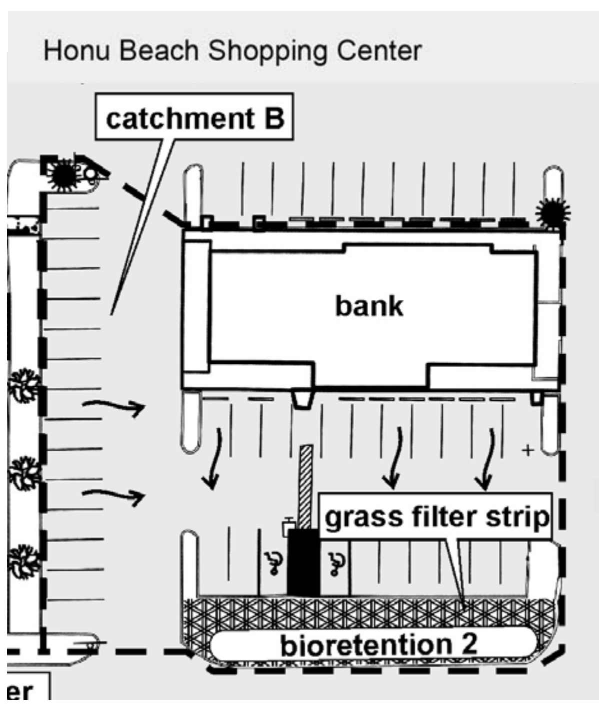


Figure 3.14 BMP Selection at the Honu Beach Shopping Center

Final BMP Design

The best BMP for use at our site is a bioretention area. Bioretention is a great way to provide treatment for parking lots because landscaped parking lot islands can easily be designed/converted to accept stormwater. Bioretention can be on-line or off-line facilities. In this case, due to the small size of the site, it can be designed to accept surface runoff from the parking lot (on-line), with a grass filter strip for pretreatment. An overflow is provided to convey flow from larger storms into the closed system.

In addition, there are ways to incorporate more low-impact techniques at this site. Rooftop runoff could be collected and used to water the landscaping. Permeable pavers could be used for the overflow parking or parking spaces could be reduced based on the need at the site.

3.7.2 Treatment Volume Calculation

Aloha Estates is a hypothetical medium-density residential development located in Kapa'a, Kauai (Figure 3.15). It consists of approximately 180 ¼-acre lots, with approximately 28,000 linear feet of 48-ft wide residential roads. The development covers 44 acres, with 30 acres of impervious surfaces (roads, driveways, sidewalks, and rooftops. The annual rainfall for its location is approximately 50 inches/year. The following steps can be used to determine the $WQ_{v,}$ as described in Section 3.3:

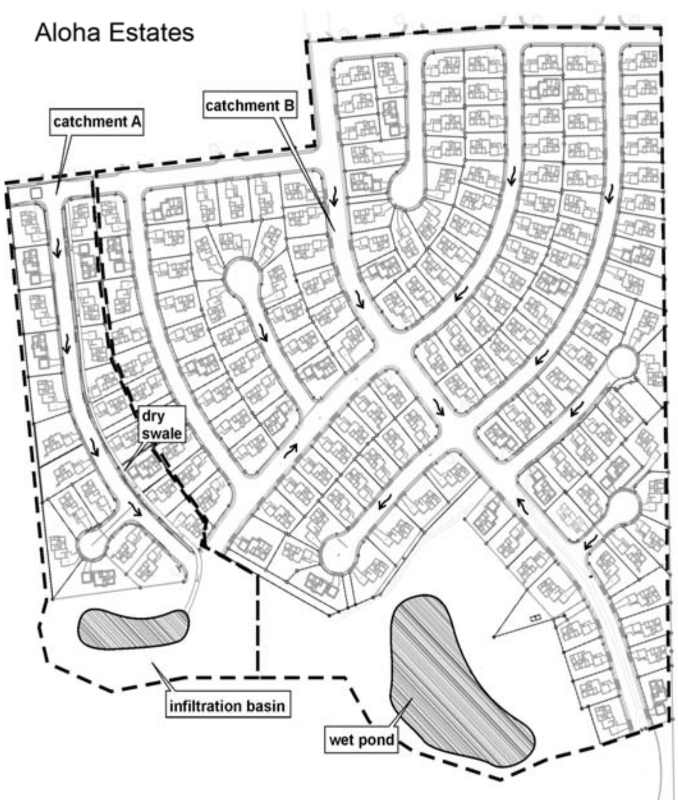


Figure 3.15 Hypothetical Medium-density Residential Development - Aloha Estates

1. Define Site Area and Impervious Cover

The total site area is 44 acres. The impervious cover percentage is 30 acres/44 acres = 68%.

2. Compute Runoff Coefficient for Site

The volumetric runoff coefficient is defined based on the following equation:

$R_v = 0.05 + 0.009\ (I) =$
$0.05 + 0.009\ (0.68) = 0.056$

3. Determine Appropriate Water Quality Storm (S)

Our site has an annual rainfall of 50 inches/year, which falls into the Zone No. 2 category from Table 3.2 in Section 3.3). The appropriate water quality storm depth for this site is S = 1.0 inch.

4. Compute Water Quality Volume (WQ_v)

The WQv expresses the cubic feet of runoff that must be treated in an acceptable stormwater treatment practice, and is computed as:

$WQ_v = (R_v)\ (S)\ (A)\ (3{,}630) = (0.056)\ (1.0)\ (44\ ac)\ (3{,}630) = 8{,}944\ cf$

Where = A = total site area, in acres

5. Select Appropriate Best Management Practice (BMP)

The final step is to select appropriate BMPs to treat the WQ_v. For this project, the designer chose to utilize dry swales, an infiltration basin, and a wet pond to treat stormwater runoff. LID techniques could be used to reduce the WQ_v required, such as using permeable pavers for the sidewalks and driveways, directly infiltrating roof runoff or capturing it in rain barrels, reducing road widths, changing the pattern of development to reduce cul de sacs, and using rain gardens in the center of the cul de sacs.

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4 Wastewater Management

4.1 Introduction

Wastewater management is an important component of watershed protection. Wastewater discharges can affect drinking water supplies, fresh water systems and coastal resources. Wastewater throughout Hawaii and the rest of the country is managed through a variety of onsite systems, clustered or small wastewater treatment facilities, or larger, centralized wastewater treatment plants. Hawaii Administrative Rules, Title 11, Department of Health, Chapter 62, Wastewater Systems govern the disposal and treatment of wastewater in Hawaii (this rule will be summarized below).

The goal of this chapter is to identify how onsite, cluster and centralized wastewater systems function and describe how wastewater affects groundwater and surface water quality, focusing on impacts from nitrogen, phosphorus, and pathogens discharged in wastewater effluent. This description is followed by a discussion of alternative technologies for wastewater treatment and disposal that can be used to mitigate water quality issues with effluent disposal. The technologies described here are a sampling of those available for onsite systems and small wastewater treatment facilities, and references and web links are provided for additional information. Included in this discussion is a brief description of wastewater reuse, including the use of treated effluent for agricultural fields, landscaped areas and golf courses which is quite common in Hawaii.

Finally, opportunities for protecting water quality through wastewater management are described. A series of management approaches are identified, highlighting innovative wastewater solutions that focus on cluster development or "smart growth" village center areas. In addition, case studies are provided that highlight both the uses of alternative technologies, as well as innovative management approaches.

Regulatory Overview

(Excerpted from the National Small Flows Clearinghouse National Summary Citations accessible at http://www.nesc.wvu.edu/nsfc/nsfc_national_summaries_1.htm)

Through Chapter 11-62, the Hawaii Department of Health (DOH) seeks to ensure that the use and disposal of wastewater and wastewater sludge does not contaminate or pollute any valuable water resource, does not give rise to public nuisance, and does not become a hazard or potential hazard to the public health, safety and welfare. The DOH also ultimately hopes to ultimately institute regional sewage collection, treatment and disposal systems which are consistent with state and county wastewater planning policies. Off-site treatment and disposal systems, followed in priority by onsite systems, meeting health and environmental standards will be allowed whenever they are consistent with state and county wastewater planning policies and on the premise that these systems will eventually connect to regional sewage systems. Individual wastewater systems may be utilized in remote areas and in areas of low density. Chapter 11-62 applies statewide and can become more stringent on the local level if approved by the state.

Chapter 11-62 also gives the mayor of each county the ability to ask the Director of the DOH to form a county wastewater advisory committee to review and make recommendations to the director on the application of Chapter 11-62 on matters which are unique to each county, on the establishment of critical wastewater disposal areas, on proposals which are not specifically addressed by Chapter 11-62, and upon the Director's request, for applications for variances. Critical wastewater disposal areas may be established by the Director in each county based on concerns relating to a high water table, impermeable soil or rock formations, steep terrain, flood zone, protection of coastal waters and inland surface waters, high rate of cesspool failures, and protection of groundwater resources.

4.2 Approved Wastewater Treatment Technologies

Wastewater Treatment Technologies Approved for use in Hawaii include:
- Conventional - Aerobic treatment units, septic tanks, soil absorption beds and trenches, absorption or seepage pits, dry wells, sand filters, mounds, and evapotranspiration beds.
- Alternative - Gravelless chambers, some gravelless pipe systems, constructed wetlands, composting and incineration toilets, and aerobic systems with NSF Standard 40 certification.
- Experimental - Each installation requires local Board of Health approval and dedicated site for replacement with conventional or alternative systems. No specific products or technologies are identified as experimental, but an experimental technology can be approved on a case-by-case basis.

Provisions exist for the Director of Health to allow other innovative and alternative technologies. The DOH allows the technology to be used on an experimental basis during which performance data are gathered over a period to demonstrate that the technology functions as described.

All site evaluations and wastewater system design are required to be done by a professional engineer licensed in Hawaii. A percolation test or soil characterization is required as part of the site evaluation. There is a minimum lot size of 10,000 square feet for the use of an onsite wastewater system in Hawaii. Minimum setback/separation distances include:

	Septic Tank (feet)	Drainfield (feet)
Dwelling/structure	5	5
Well/private well	-	1,000
Surface water	50	50
Property lines	5	5
Seasonal high water table/limiting layer	-	3
Wetlands	50	50

On December 9, 2004, a number of amendments to Chapter 11-62 were signed into law by the Governor. Major changes include:

- Establishes criteria for wastewater sludge (biosolids) to be used or disposed;
- Requires wastewater treatment facilities to obtain either an individual wastewater permit or coverage under the general permit for treatment works;

- Requires cesspool pumpers and grease trap haulers to be registered with the Department of Health;
- The Department's Reuse Guidelines and Animal Waste Guidelines are referenced in the rule;
- Establishes effluent quality for recycled water systems and incorporates the Department's Spill Protocol into the rules;
- Revises many requirements for individual wastewater systems;
- Requires that septic tanks used in Hawaii meet the standards set by the International Association of Plumbing and Mechanical Officials (IAPMO);
- Adds processing fees to applications for new and modified individual wastewater systems; and
- Allows the Department to issue field citations for specific types of wastewater violations.

It should be noted that Hawaii still allows large capacity cesspools (LCCs) to be designed, constructed and utilized in some wastewater disposal settings. However, in 2000 the U.S. EPA banned the construction and use of new LCCs. Furthermore, as of 2005, the EPA mandated that all existing LCCs be either upgraded or closed. A cesspool is considered to be a LCC if it receives sanitary waste from multiple dwellings (such as a duplex) or receives waste from 20 or more persons per day from a non-residential building. Cesspools serving single family homes are not affected by this EPA ruling.

In Hawaii, Chapter 11-62 allows cesspools to serve duplexes and non-residential buildings that may be used by 20 or more persons per day. Although these uses do not violate the provisions of Chapter 11-62, they do violate U.S. EPA regulations and may result in fines of up to $32,500 per day for the owner of a LCC. It is possible to have a cesspool approved by the DOH that may result in federal fines for its owner. DOH will notify building permit applicants proposing to use a LCC of the potential federal rule violation and recommend that the wastewater system be revised.

4.2.1 Septic Systems/Wastewater Treatment Facilities

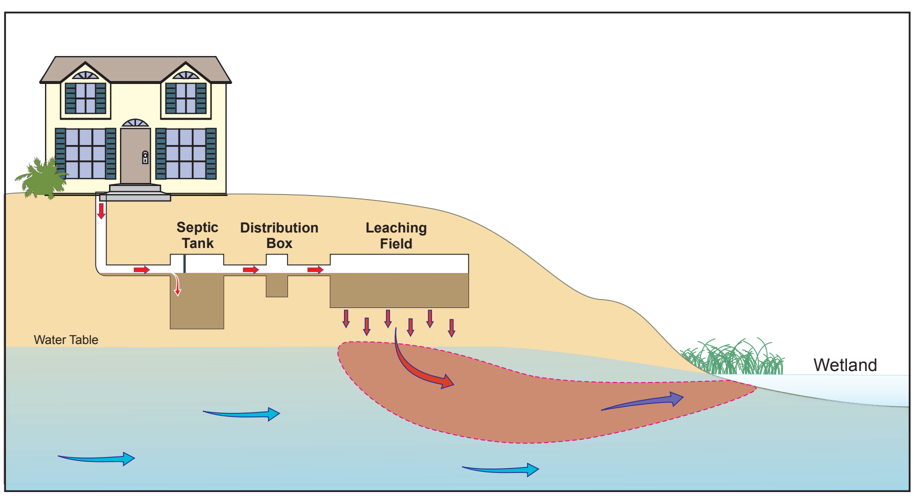


Figure 4-1. Septic systems are comprised of a septic tank and a leaching facility .

The septic tank provides for the settling out of solids and some biological treatment of the wastes. The leaching facility disposes of the liquid wastes into the subsurface environment. Cesspools are essentially either a covered hole or pit for receiving drainage or sewage, as from a house. There is no septic tank, and the settling of solids and the disposal of liquid wastes occurs in the same place. As no biological treatment of wastes occurs as in a septic tank, a cesspool is the least protective method of wastewater disposal (other than direct discharge of sewage onto the ground or in a water body, which is illegal throughout the United States).
If septic tanks are not properly maintained (pumping once every three years is recommended for single family homes), solids may pass out of the tank and clog the leaching facility. This can cause hydraulic failure of the system resulting in the possible backing up of wastewaters into the building or effluent breaking out onto the land surface. The latter case often offers a direct route of transport to a freshwater resource.

Conventional septic systems are designed to control pathogenic bacteria and are less effective in treating other potential pollutants. Leaching facility effluents contain approximately 40 to 60 mg/l nitrogen and 8-38 mg/liter phosphorus (Hall, 1975). Nitrogen compounds generally move through the groundwater system relatively intact, ultimately reaching water bodies. Viruses, being much smaller than bacteria, also move easily through soils at the speed of groundwater. Because their inactivation times in groundwater are approximately 120-200 days, they have been documented to move distances greater than 300 feet in soils. If a septic system is located too close to a water body, viruses may reach surface waters. Septic systems sometimes introduce hazardous wastes into the groundwater if the owner uses septic cleaners or improperly disposes of household hazardous wastes.

The cumulative effects of many single family septic systems on nutrient, pathogen, or hazardous waste levels in down-gradient waters can be very significant. These impacts are dependent upon septic system location and density relative to receiving water bodies.

Wastewater treatment facilities are a source of direct discharges to water bodies. In some cases in the southwestern United States, these water discharges are the main source of water within the streams. Although partially treated, these discharges can still contain materials such as metals and other organics not treated in the wastewater treatment facility.

Onsite Septic Systems Impacts to Water Quality

Onsite septic systems typically consist of a septic tank and a leaching or disposal facility (Figure 5-1). Wastewater that flows through the system and reaches the underlying aquifer still contains dissolved materials such as salts, nutrients, solvents, toxic compounds, metals, and soluble pesticides. This wastewater also still contains pathogens such as bacteria and viruses and some very small particles of insoluble materials. Water quality concerns associated with the primary constituents of septic system effluent are described below.

Nitrogen: Nitrogen in septic system effluent is present in concentrations well above the 10-mg/L federal drinking water standard. Effluent from a properly operating septic system typically contains 40 milligrams per liter (mg/L) nitrogen (H&W, Inc., 1998). This is four times higher than the Drinking Water Standard. If one is drinking water from a private well that contains nitrogen at or near the 10-mg/L standard, it is possible the water contains approximately 25% recycled wastewater effluent. Elevated levels of nitrate in drinking water can cause serious problems for infants, who could develop methaglobamenia (Blue Baby Syndrome), if the water is used in the preparation of formula or drinking water. It is, at elevated levels, a potential concern for adults as a carcinogen (Weyer, et al., 2001). Nitrate-nitrogen in septic system effluent does not precipitate or sorb to the soil materials through which it travels in groundwater and further attenuation is only caused by mixing and dilution with native groundwater. The effluent travels as a plume as it leaves the septic system, and the mixing only occurs as it either reaches a surface water (such as the coast) or is withdrawn through a pumping well.

Excessive nitrogen has been found to accelerate eutrophication in some coastal and estuarine waters (Wetzel, 1983). The critical concentration for marine waters can be as low as 0.2 mg/l, depending on the rate of tidal flushing (Nielson, 1981; Buzzards Bay Project, 1991). Excessive nitrogen loading to marine and brackish ecosystems can cause algal blooms, decreased water clarity, and declines in eelgrass beds which are important shellfish and finfish habitat.

<u>Phosphorus</u>: Phosphorus concentrations in typical septic system effluent are far in excess of acceptable levels for surface water bodies and are known to be major causes of algal blooms and eutrophic conditions in ponds, lakes and streams. Unlike nitrogen, phosphorus reacts with, or is sorbed to, sediments and rock particles in the ground and initially does not travel more than a few feet from a septic system leaching facility. However, after years of application, the reactants and sorptive capacity of sand and gravel soils becomes exhausted. Phosphorus will gradually be transported further and further form the septic system, ultimately to a discharge point in a wetland or surface water (such as pond or the ocean).

<u>Bacteria and Viruses</u>: Pathogenic microorganisms (bacteria and viruses) are also found in domestic wastewater. In a properly operating septic system, the effluent does not discharge on land surface and the potential for human contact and infection from bacteria is low. The movement and survival of bacterial contaminants in the groundwater has been studied extensively. It has been shown that most bacteria are attenuated within a short distance of the point where they leave the leaching facility; usually between one to thirty metres in permeable sands and gravel (Canter and Knox, 1986). Bacteria are attenuated by adsorption to solid soil and aquifer materials and by death in slow-moving groundwater. In malfunctioning systems, pathogenic organisms can be discharged to the surface and contaminate soil and surface waters.

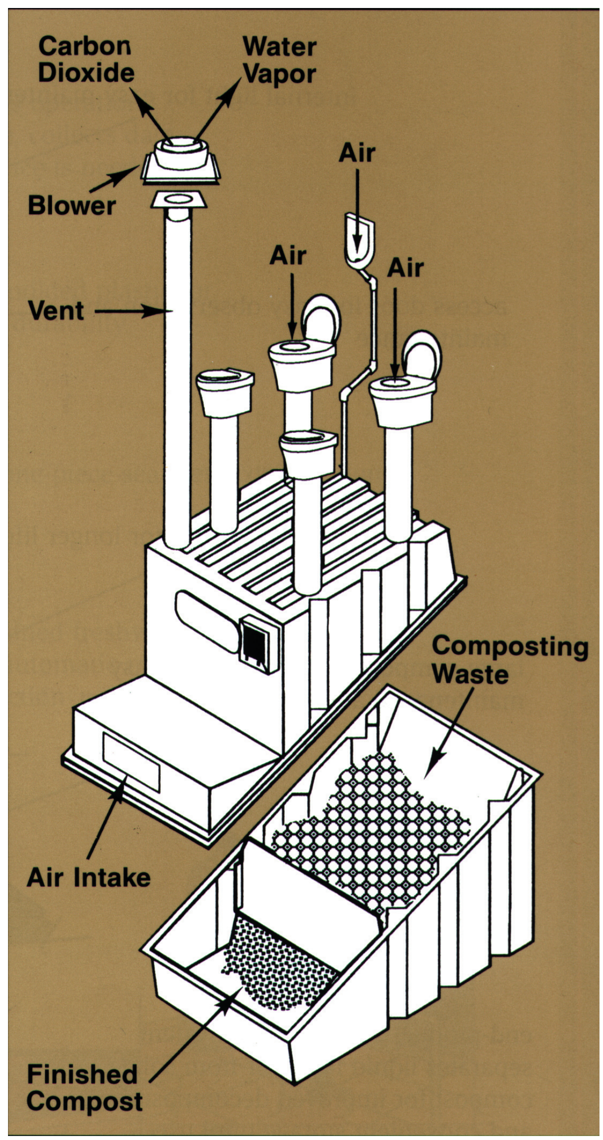
Research (Yates, 1987) indicates that viruses from septic system effluent can persist over longer periods of time in groundwater than in surface water, and the transport of viruses in groundwater occurs over longer distances and over longer periods of time than does the transport of bacteria. Viruses are ultramicroscopic particles, ranging from about 20 to 200 nanometres in diameter of a host cell. Only infected individuals can introduce them to septic system effluent. Unlike bacteria, they do not require nutrients in groundwater to survive and, therefore, can persist in groundwater for longer periods than bacteria.

Attenuation of viruses in groundwater is dependent on time and groundwater temperature. The colder the groundwater, the longer the viruses will survive. The longer the viruses are in the ground, the more they die off, until they eventually become inactive and no longer a health threat. In order to determine how far viruses may travel in the ground, the inactivation rate for virus in groundwater is compared to the rate of groundwater flow. The overall extent of travel will also be influenced by the height of the leaching facility above the water table, as viruses will be attenuated in this zone before they reach the aquifer. See Chapter 3 for more detail.

4.3 Alternative Onsite Wastewater Technologies

An alternative onsite system is an onsite treatment system other than a conventional septic tank and leach field design. Alternative systems are used to accommodate a variety of site conditions (e.g., high ground water, low-permeability soil) and/or to provide additional treatment. Sometimes systems are classified as alternative because, even though they make use of a conventional septic tank and leach field, they also utilize an alternative plumbing fixture such as a composting toilet. Other examples of alternative wastewater technologies include recirculating sand filters, intermittent sand filters, trickling filters, sequencing batch reactors, aerobic treatment units and nitrate reactive media.

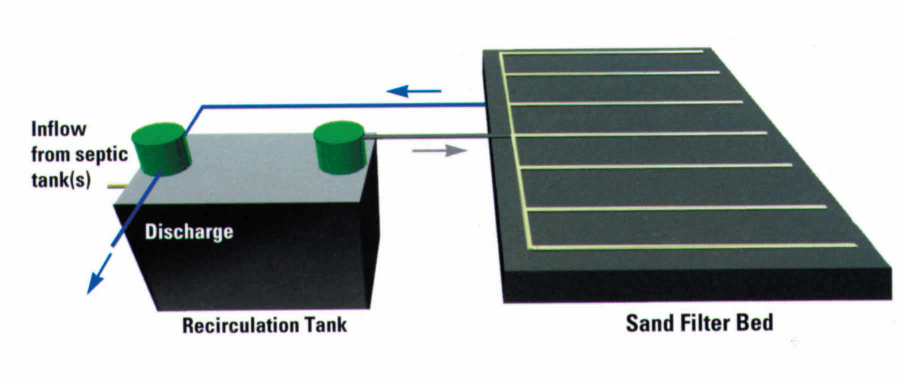
The same alternative treatment technologies used in onsite systems can be scaled up for use in cluster or centralized or community systems. The information that follows is not an exhaustive listing of all the alternative wastewater technologies available.



<u>Composting Toilets</u> (excerpted from U.S. EPA's *Water Efficiency Technology Fact Sheet – Composting Toilets*, 1999)

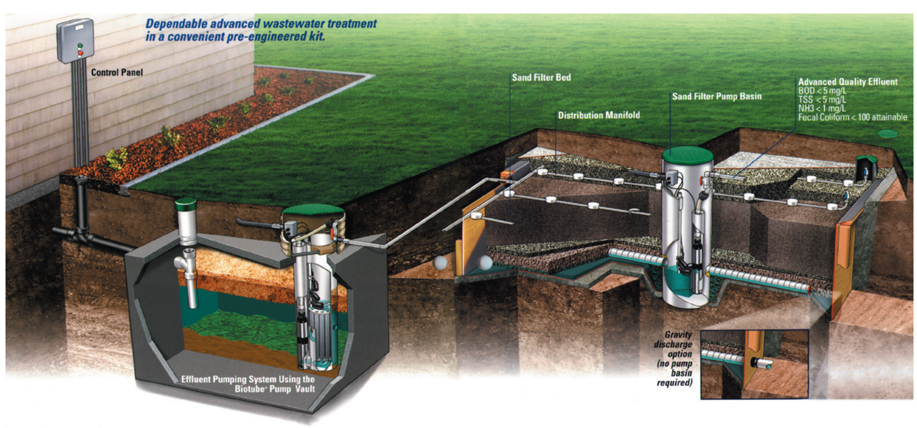
Composting toilets have been an established technology for more than 30 years and they require little to no water, enabling them to provide a solution to sanitation and environmental problems in unsewered, rural and suburban areas. The system relies on unsaturated conditions where aerobic bacteria break down waste. The resulting "humus" must be disposed of either through burial or removal by a licensed septage hauler. A typical composting toilet is a well-ventilated container that collects and composts waste (including toilet paper) in a large container installed below the toilet in a basement or in a small compartment located directly beneath the toilet. Composting toilets can be used almost anywhere a flush toilet can be used, but typically appear in seasonal homes, homes in remote areas and recreation areas. Some examples of composting toilets include the Clivis Multrum, the Biolet and the Carousel to name a few.

<u>Recirculating Sand Filters</u> (excerpted from U.S. EPA's *Decentralized Systems Technology Fact Sheet – Recirculating Sand Filters*, 1999)



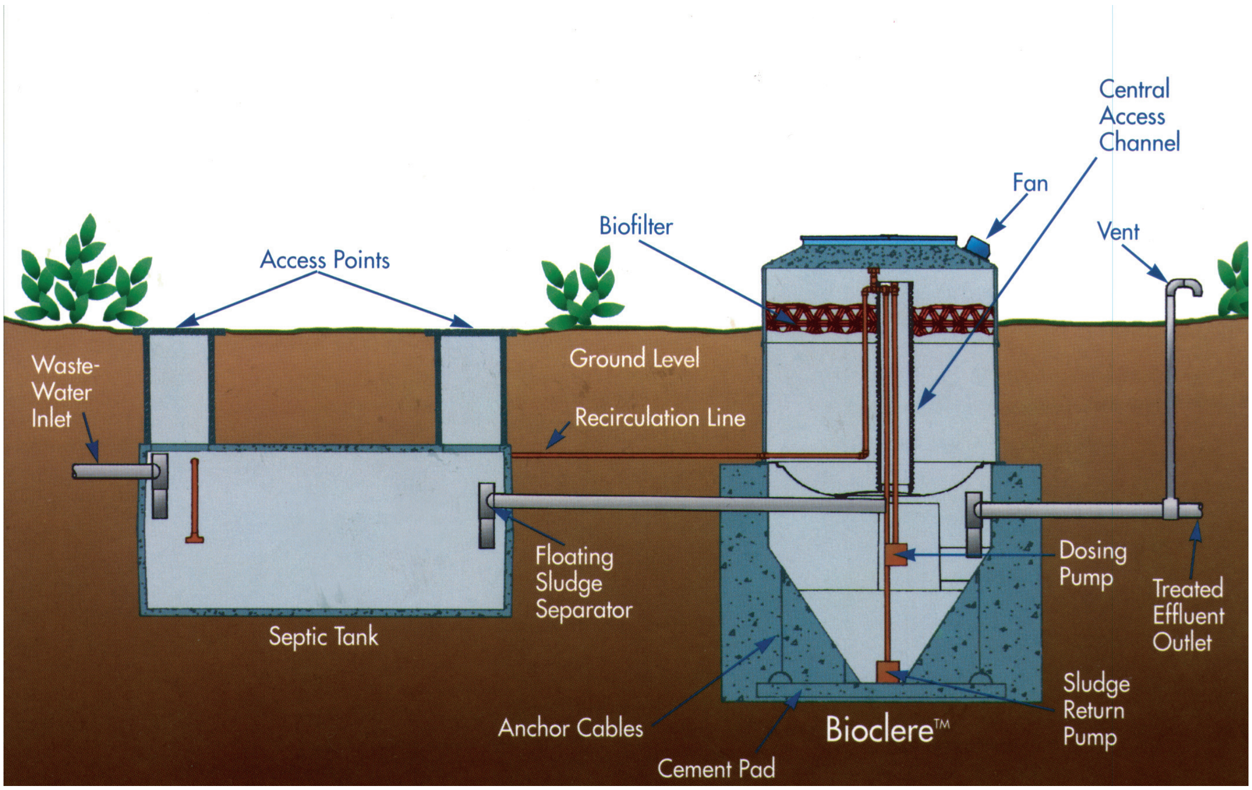
A recirculating sand filter (RSF) is a modified version of a single-pass open sand filter. It was designed to alleviate odor problems associated with open sand filters through recirculation, which increases the oxygen content in the effluent distributed on the filter bed. RSFs can be used on sites that have shallow soil cover, inadequate permeability, high groundwater and limited land area. The most important treatment process in a RSF is a biological one, and RSFs typically produce a high quality effluent with about 85% to 95% biological oxygen demand (BOD) and total suspended solids (TSS) removal. In addition, RSFs may also remove up to 50% of nitrogen within the treated effluent. RSFs are typically found serving subdivisions, mobile home parks, rural schools, small municipalities and other small wastewater generators such as individual family residences. Some manufacturers of RSFs include Ashco, American Manufacturing Company and others.

<u>Intermittent Sand Filters</u> (excerpted from U.S. EPA's *Wastewater Technology Fact Sheet – Intermittent Sand Filters*, 1999)



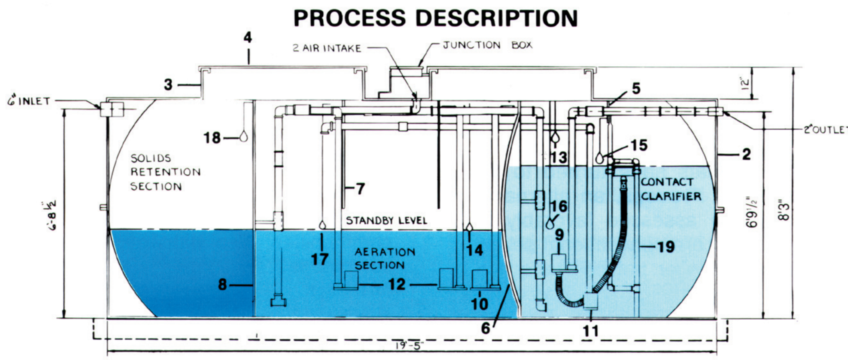
Intermittent Sand Filters (ISFs) have 24-inch deep filter beds of carefully graded media (typically sand but not always). The surface of the bed is intermittently dosed with effluent that percolates in a single pass through the sands to the bottom of the filter. After being collected from the underdrain, the treated effluent is transported to a line for further treatment or disposal. ISFs are typically built below grade in excavations 3 to 4 feet deep and lined with an impermeable membrane where required. Discharges from ISFs are usually of high quality and can be used for drip irrigation or for surface discharge after disinfection. Typical concentrations of BOD and TSS are 5 milligrams per liter or less and nitrification of 80% or more of applied ammonia is usually achieved. ISFs serve the same users as RSFs, and manufacturers include Orenco Systems, Inc., Infiltrator Systems, Inc. and others.

Trickling Filters (excerpted from U.S. EPA's *Onsite Wastewater Treatment Systems Technology Fact Sheet 2 – Fixed Film Processes*, 2002 and *Decentralized Systems Technology Fact Sheet – Types of Filters*, 2000 as well as information from the Caribbean Environment Programme Technical Report #43, 1998 accessed at http://www.cep.unep.org/pubs/Techreports/tr43en/Low%20cost.htm)



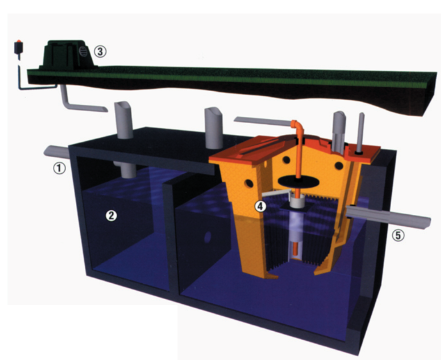
Trickling filters are one form of fixed film systems. Fixed film systems are biological treatment processes that employ a medium (such as peat) that will support a biomass on its surface and within its porous structure. Other filter media include foam, crushed glass and textile chips. In a trickling filter, the medium is held in place and is stationary relative to the wastewater flow. Much research has been conducted on peat in the northeastern United States, where peat is readily available. Peat filters used for onsite wastewater treatment remove about 60% to 90% of BOD, but no long term data are available. As peat is a natural material, significant variations in composition can occur. Several manufacturers of peat trickling filters enclose the peat in fiberglass housing or polyethylene modules. Peat (and other media) trickling filters have been installed at single and multiple family residential dwellings, elementary and high schools, commercial retail establishments and restaurants. Manufacturers include firms such as Oliver, Mangione, McCalla & Associates in Canada, Bioclere, Waterloo Biofilter System, Inc. and others.

<u>Sequencing Batch Reactors</u> (excerpted from U.S. EPA's *Wastewater Technology Fact Sheet – Sequencing Batch Reactors*, 1999)



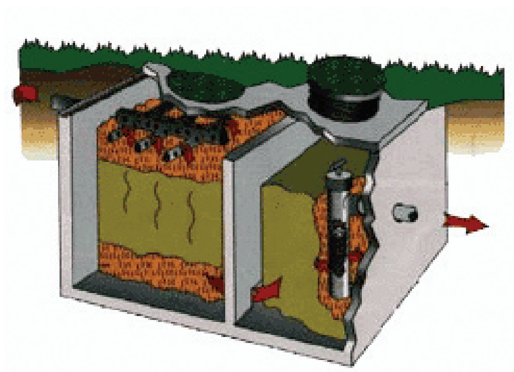
The sequencing batch reactor (SBR) is a fill-and-draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single "batch" reactor, treated to remove undesirable components and then discharged. To optimize performance, two or more batch reactors are used in a predetermined sequence of operations. An advantage of this system is its ability to manage and treat low or intermittent wastewater flows. In essence, the SBR is an activated sludge system that operates in time rather than place. SBRs can achieve good BOD and nutrient removal, with a BOD removal efficiency of approximately 85% to 95%. Total nitrogen can be reduced to as low as 5-8 milligrams per liter. SBRs are in use at condominiums, mobile home parks, shopping centers, marinas, golf courses, resorts, campgrounds, motels, restaurants, apartment buildings, small municipalities and neighborhoods, and can be scaled for either small or large applications. Manufacturers include the Walden Corporation, Cromaglass, Amphidrome and others.

<u>Aerobic Treatment Units</u> (excerpted from U.S. EPA's *Decentralized Systems Technology Fact Sheet – Aerobic Treatment*, 2000)



Aerobic treatment units provide a suitable oxygen rich environment for organisms that can reduce the organic portion of the waste into carbon dioxide and water in the presence of oxygen. Aerobic systems are similar to septic systems except that the treatment process requires oxygen, therefore the units use a mechanism to inject and circulate air inside the treatment tank. These mechanisms include diffused air, sparged turbine, or a surface entrainment device. Two aerobic primary treatment systems have been adapted for onsite use: suspended growth, where microorganisms are suspended within the waste stream, and fixed film, where the microorganisms are attached to an inert medium within the waste stream. Suspended growth units can provide for a 70% to 90% BOD reduction in household wastewater. Aerobic treatment units are suited for use in single family dwellings, clustered subdivisions, restaurants and other commercial applications as well as renovation of biologically failed septic systems. Manufacturers include Bio-Microbics, Inc. and Smith & Loveless, Inc. (FAST systems), Jet, Inc., Norweco, Inc. and others.

Nitrate Reactive Media (NITREX™) (excerpted from the U.S. EPA Region 1 website accessed at http://www.epa.gov/NE/assistance/ceit_iti/tech_cos/waterloo.html)



In this system, a nitrate-reactive media (such as wood chips) converts nitrate to inert nitrogen gas (denitrification). The NITREX™ reactive media is contained in a prefabricated tank, or for larger installations in an engineered excavation. Nitrate contaminated wastewater is gravitationally fed through the treatment module. For septic tank applications, an oxidative pre-treatment step is required to first convert ammonium ($NH4+$) to nitrate ($NO3-$), then the NITREX™ filter performs the reductive denitrification step. Pre-treatment can be achieved with any of the existing oxidative technologies, for example sand filters, commonly used in septic tank treatment. The nitrate-free effluent from the NITREX™ filter is simply discharged to a conventional tile bed. The NITREX™ filter is passive and essentially maintenance free. It reportedly provides almost 100% nitrate removal in a low cost, easy-to-install process. Manufacturers include Wastewater Science, Inc. in Canada and Lombardo Associates, Inc. in the United States.

4.4 Clustered Wastewater Systems

A clustered wastewater system is a collection and treatment system under some form of common ownership that collects wastewater from two or more dwellings or buildings and conveys it to a treatment and disposal system located on a suitable site near the dwellings or buildings. These systems can serve a small subdivision, an apartment building, a senior living complex, or condominium units. Clustered wastewater systems can be very useful for rural servicing, as they can allow for denser, village development to be maintained by collecting wastewater for treatment and disposal away from private water wells or a community well. Clustered systems also allow a community flexibility in providing wastewater treatment and disposal services based on facility use (e.g., office complex or single family homes?) and facility location (e.g., within a critical wastewater disposal area or outside of a critical wastewater disposal area?).
Therefore, it is entirely possible that several clustered systems or a combination of onsite and clustered systems may be best to meet a community's wastewater treatment and disposal needs. The advantages gained by using clustered systems versus onsite systems include greater control

over maintenance of the system and therefore wastewater treatment, an enhanced ability to prevent cross-connections between wastewater treatment systems and private or community wells, and the ability to have multiple wastewater solutions within a community based on its unique geographic and development characteristics. Administrative costs to a community can also be reduced as clustered systems are typically privately maintained through a homeowners or condominium association or by a corporate entity with DOH oversight.
Cluster systems offer a number of options in terms of collection, pretreatment, final soil absorption, and management of the system. Several types of alternative sewer systems such as pressure, small diameter gravity, and vacuum sewers can be used to collect and transport wastewater. Pressurized alternative sewer designs are appropriate for hilly or extremely flat terrain, shallow bedrock, high water table, or anywhere the costs and environmental impact of excavating for traditional gravity sewers would be prohibitively expensive. Pressure sewers are subdivided into grinder-pump systems, which shred sewage solids at each individual connection prior to pumping the waste into the collection system, and septic tank effluent pumping (STEP) systems, which use septic tanks located at each connection to remove grit, grease and settleable solids prior to pumping into the collection system.

Small-diameter gravity sewer systems are another alternative sewer option for small communities. These systems use gravity, rather than pumps or pressure, to collect and transport wastewater to a facility for treatment. Like STEP systems, septic tanks at each individual connection remove most of the solids from the wastewater so the sewers transport relatively solids-free effluent. Vacuum sewers rely on suction, created at a central pumping station and maintained in the small diameter mains, to draw and transport wastewater through the system to final treatment. When wastewater in a small holding tank at each connection reaches a certain level, a sensor opens a pneumatic valve and the tank's contents are sucked into the line by the vacuum. Vacuum sewers are best suited for areas with flat or gently rolling terrain, as they can usually only transport waste about 20 feet uphill.

The pretreatment facility in a cluster system is often a larger version of ones found in some individual onsite systems, such as aeration, constructed wetlands, or media filters, followed by disposal of the treated effluent into a soil absorption system. Some cluster systems empty into a conventional sewer main that leads to a centralized municipal treatment facility. This may be very cost effective for communities that have this option. There are also other disposal options. If a proper site and soil area can be located nearby (such as a community park or facility such as a baseball field), it may be practical to dispose of treated sewage in a larger subsurface leachfield or drainfield similar to the smaller ones used for individual homes or businesses with onsite septic systems. Another disposal option may be drip irrigation, which places small amounts of treated wastewater effluent a few inches below ground surface where nutrients can be taken up by the plants in the lawn or ball field rather than leaching into groundwater.

4.5 Centralized Wastewater Systems

A centralized wastewater system is a managed system consisting of collection sewers and a single treatment plant used to collect and treat wastewater from an entire service area. Traditionally, such a system has been called a publicly owned treatment works (POTW). In many cases, these larger municipal systems transport sewage away from homes and businesses in large diameter gravity sewers to a central plant where it is treated and eventually discharged into a waterway. A centralized wastewater system is a good wastewater solution in larger densely populated areas, since the cost of a municipal sewage system is lower if it can be distributed over a larger number of users. However, centralized treatment systems operated by small communities can perform poorly because of a lack of expertise and funding to maintain and update the facility. Sewered small communities which treat and discharge wastewater account for most of the non-compliance violations, according to the U.S. EPA.
When maintained properly, centralized wastewater systems can offer high levels of public health and environmental protection. Centralized systems are also excellent in terms of supporting high-density, village centers, as wastewater from these centers can be transported elsewhere for treatment and disposal. In addition, a properly maintained centralized system virtually eliminates the possibility of cross-connections between wastewater treatment and private or community drinking water wells as the single discharge point can be optimally located away and downgradient of drinking water sources.

4.6 Wastewater Reuse

(Excerpted from information provided by the Hawaii Water Environment Federation web site accessed at http://www.hwea.org/wtrreuse.htm)

In Hawaii and around the United States, population growth and development pressures are straining the fresh water resources of many communities. To combat water shortages, more and more communities and states are investigating wastewater reuse or recycling. In Hawaii, there are three classifications of recycled water based on regulatory definitions (§11-62-03 and §11-62-27). The classifications indicate levels of purity and determine how the water is monitored. The water is not recycled if it does not meet the required level of quality.

R-1 is the highest quality recycled water. This water has gone through filtration and disinfection that makes the water safe for use on lawns, golf courses, parks, and other places that people frequent. In Hawaii, more and more projects are using R-1 water.

R-2 is slightly lower quality recycled water. R-2 is secondary (biologically) treated wastewater that has also been disinfected. Its use requires more caution and restrictive controls than R-1 water.

R-3 is the least pure class of recycled water. R-3 quality water is wastewater that has been treated to the secondary level. It can only be used for irrigation at places where people rarely go. Recycled water is utilized on most of the main islands in Hawaii. Golf courses, agriculture, and landscapes are irrigated with recycled water. Some of the golf courses that use water include the Experience at Koele, Ka‘anapali Golf Course, Hawaii Kai Golf Course, Kaua‘i Lagoons and Waikaloa Resort. Agricultural uses include seed corn irrigation on Maui and Kaua‘i and at

Hawaii Reserves on Oahu where bananas, papayas, and ornamental plants are grown. Landscape irrigation projects include Kalama Park and the Kihei Public Library on Maui, Mauna Loa Highway beautification on Moloka'i and the Brigham Young University-Hawaii campus on Oahu.

On Maui, the Kihei Effluent Reuse System is the first application in Hawaii of an effluent reuse system pressurized by an elevated closed reservoir, making the effluent available to customers on a continuous basis. Customers can simply connect to the system and use the effluent without the use of booster pumps. Purple fire hydrants let people know that they are connecting to the reclaimed water system. The system has met its goal of providing the County of Maui with a system that is beneficial to the community by preserving its potable water resources, and utilizing reclaimed water for irrigation of parks, landscape areas and a golf course, and for fire protection. The reclaimed water is also used by a major agricultural operation, Monsanto Corporation, for the production of high quality seed corn that is marketed worldwide. The system has proven to be easy to operate and reliable, and has met the needs and expectations of the County.

4.7 Servicing Options for Rural Communities

When it comes to providing wastewater services for a rural community, it is usually a balancing act to provide both clean drinking water and effective wastewater disposal while striving to maintain the village character that makes a rural community appealing. There is a continuum represented by onsite water and wastewater services versus centralized water and wastewater services that contains both positive and negative features or outcomes. This continuum can be expressed visually by the "wheel" depicted in Figure 4-2 below. Positive aspects of the continuum are shown in black text and negative aspects of the continuum are shown in white text.

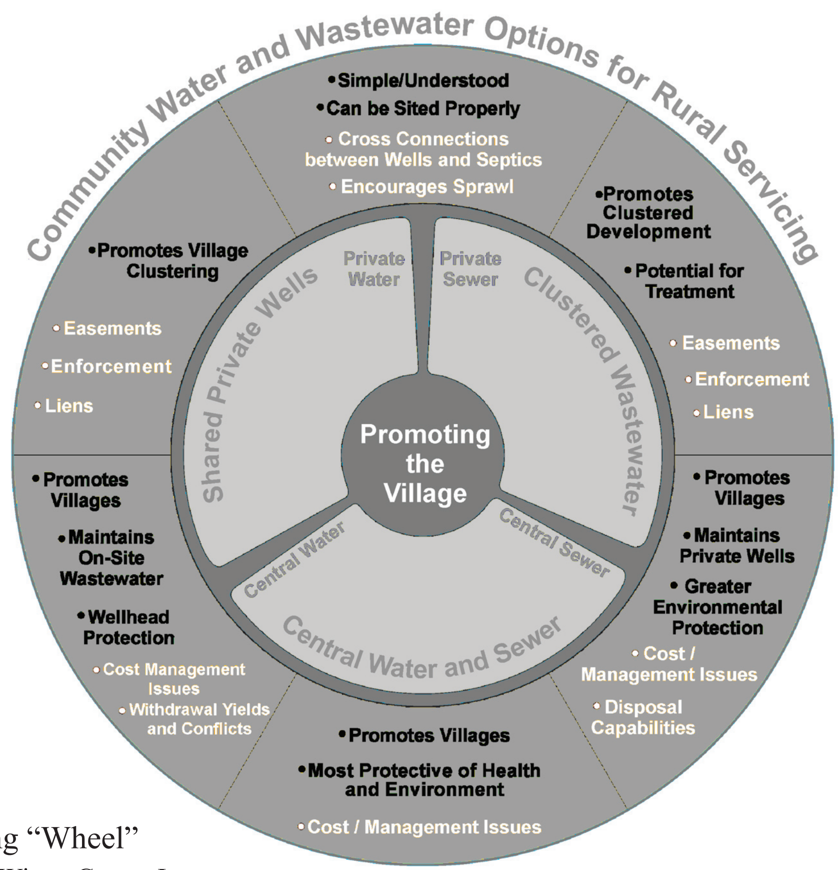


Figure 4-2.
The Rural Servicing "Wheel"
Source: Horsley Witten Group, Inc.

The main concern with using both private wells and septic systems in any setting is the cross contamination of the private well caused by the pumping of groundwater containing septic system effluent. The effluent can be from the septic system on the same lot, or from one located on an adjacent or nearby lot. Small lots and denser development increases the potential for cross contamination as wells and septic systems are placed closer together, often close to the required setback distance. If very small lot sizes are desired, it may not be feasible to use private services, as it will not be possible to maintain the required setbacks.

The growth of a village using private services can also be limited by the local soils or geologic conditions that may limit the use of onsite septic systems or private wells. Tight soils or shallow depths to groundwater on a small lot may make it impossible to properly site a septic system. The ability to install a well that provides an adequate volume of potable water may also be limited. If the village is adjacent to surface waters or wetlands, the use of onsite septic systems may impact these resources through discharges of nitrogen and phosphorus.

Adjacent properties can utilize a shared septic system to discharge wastewater, eliminating the need for a system on each individual lot. This approach can be used in areas where septic systems are being upgraded, and there are space constraints on some lots, but not on others. The shared system can be a standard system, or could include components to provide advanced treatment. One caveat relating to the use of shared systems is that they can create more development than intended. For example, Lot A and Lot B are adjacent lots that are currently vacant. The physical characteristics of Lot B may be such that it cannot support an individual on-site wastewater disposal system and therefore no dwelling can be built. However, the physical characteristics of Lot A may be such that it can accommodate wastewater from more than just a single dwelling. In this situation, Lot B may now be built as the dwelling on Lot B will share the drainfield that is being built to service the new dwelling on Lot A. Because of the use of a shared system, a previously "un-buildable" lot has now been made "buildable," and this can be an undesired consequence of utilizing shared systems if a community is trying to control growth.

A clustered wastewater system as discussed in this workbook is essentially a larger version of a shared system, and may serve an entire subdivision. The use of a clustered system allows for greater flexibility in the siting of private wells on individual lots, and can maximize development in areas that would otherwise be limited by private well setback distances, local soils and depth to water constraints. Clustered systems can include advanced treatment, with the level of treatment a function of the environmental and public health issues in the vicinity of the system.

A village can be developed or maintained using a centralized water system, a centralized wastewater treatment system or both. The use of one or both of these systems avoids the cross contamination concerns with private wells and septic systems. Centralized water provides the opportunity to manage water quality issues better than with private wells, and centralized wastewater can offer many treatment advantages over standard septic system treatment of wastewater.

The design, construction and management of private onsite septic systems and private or public cluster or centralized service systems has evolved considerably over the last 20 – 30 years. To a great degree, this evolution has been led by the environmental, public health and land use planning conflicts that result from the pressures of increased development using onsite wastewater services.

Today, there are many examples of best practices and innovative solutions to remedy both existing problems in growing communities and optimize land use in new rural development. The information provided in the following matrix is intended to illustrate the variety of approaches and strategies to wastewater management. Benefits and drawbacks for each approach or strategy have been provided in the matrix, beginning on the next page, in terms of engineering/implementation, land use planning and public health/environmental protection perspectives.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Planning Well/Septic Locations Based on Local Hydrogeology *Knowledge of local hydrogeologic conditions can be used to optimize the locations of wells and septic systems. This approach maximizes the housing densities achievable via private, onsite servicing and minimizes the potential for cross connections that is inherent to private, onsite servicing.*	Benefits: • No added wastewater treatment is needed. • The cost of implementing this approach is minimal, especially if planned in advance. • No additional O&M for the homeowner.	Benefits: • The density of development isn't as restricted as in areas relying on standard well and septic setbacks. • Can be implemented in cluster subdivisions. Understanding local hydrogeology leads to better planning decisions.	Benefits: • The threat of cross contamination between wells and septic systems can be minimized or eliminated. • The location of sensitive environmental receptors can be taken into account prior to the construction of new subdivisions.
	Drawbacks: • Some developers could resist the approach as they may see it as an unnecessary burden, especially if local regulations do not require hydrogeological studies. • Requires good record keeping regarding the locations of wells and septic systems that may affect development.	Drawbacks: • There is a limit to the density of development that can rely on this approach. • May not work in the village core.	Drawbacks: • The use of this technique may not solve existing cross contamination problems, unless groundwater flow information is incorporated into the selection of a new well or septic location during an upgrade. • This approach does not reduce net cumulative loadings of nutrients or pathogens, which constitute threats to WHPAs, lakes, ponds, and rivers.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Clustered Septic Systems *The use of a clustered system allows for greater flexibility in the siting of private wells on individual lots, and can allow for denser development where individual septic systems would otherwise be limited by private well setback distances, local soils and depth to water constraints. Clustered systems can include advanced treatment, with the level of treatment a function of the environmental and public health issues in the vicinity of the system.*	Benefits: • Greater flexibility in siting private wells. • Can provide a higher level of wastewater treatment. • May reduce the need for centralized sewer. • Can be used to remediate existing problem systems.	Benefits: • Increased ability to develop small lots that would otherwise be limited by onsite septic system and private well setback distance constraints. • Can be used to remediate existing problems or to allow for increased use of existing properties. • Public green areas such as parks can be considered for wastewater disposal.	Benefits: • Greater flexibility in siting and protecting private wells. • Wastewater disposal locations may be sited to avoid recharge areas to sensitive receptors such as a community well. • Provides an opportunity for a higher level of effluent treatment if needed to protect environmental resources such as lakes, rivers or wetlands.
	Drawbacks: • The ownership of the system and associated sewer lines needs to be established in a manner so that all parties can rely on the system. • A mechanism is needed to provide long-term funding to maintain the system. • A clustered system is more expensive. • Higher annual operation and maintenance costs. • A structure for system maintenance needs to be worked out in advance of construction.	Drawbacks: • Allows the opportunity for development in potentially marginal areas (open space) that would not have been developable via onsite systems. Can raise concerns regarding who can connect and who cannot connect and why.	Drawbacks: • Habitat losses may increase if the use of clustered systems leads to the development of previously undevelopable areas (open space). The failure of a larger systems may have greater public health implications than the failure of a single onsite system.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Septic System Inspection and Maintenance Regulations *Septic system maintenance involves periodic inspection of the system to ensure it is working properly, and regular pumping of the septic tank to remove accumulated solids.*	Benefits: • Regular pumping reduces system failures and associated high "one time" costs for upgrades. • Prolongs the life of a septic system. • Requires no new onsite infrastructure.	Benefits: • A regular septic system maintenance program broadens the community's understanding of wastewater management issues. • Inspection and maintenance programs will increase public awareness that there are regular costs associated with wastewater disposal no matter what the system. As a result, community systems may become an option.	Benefits: • Regular pumping reduces system failures, which will lead to less effluent breakout to the ground surface. • Regular maintenance forces the property owner to locate their septic system and understand its relationship to their well. • These programs may reduce the threat of direct overland runoff of sewage effluent to sensitive water resources.
	Drawbacks: • Some homeowners resist inspection and maintenance programs to avoid pressure to upgrade their system. • Enforcement of mandatory inspections and pumping can be burdensome to municipal agencies. • A receiving facility for septage is needed.	Drawbacks: • These programs do not allow for decreased setback distances. • These programs do not resolve the planning conflict between increased village development and necessary well/septic setbacks.	Drawbacks: • Pumping does not reduce the contamination threat posed by septic systems, as effluent is still leached to groundwater between pumpouts. • Regular inspection and maintenance programs do not negate the environmental effects to sensitive water resources due to inappropriate setback distances. • These programs do not reduce total contaminant loadings to the groundwater.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Septic System Inspections and Upgrades at the Time of Property Transfer *One way to improve poorly functioning or failing systems is to require an inspection, and any necessary upgrades, at the time a property is sold.*	Benefits: • The inspection program forces homeowners to fix problems with existing or failing septic systems. • It is the simplest way to schedule a comprehensive inspection program, as all properties will transfer ownership at some point in time.	Benefits: • As with a regular pumping program, it increases the public's awareness of septic system issues. • It introduces former urban dwellers on centralized wastewater services to private septic systems. • Continued problems with individual properties can identify areas not physically suited to septic installation, furthering the City's knowledge base for future village planning.	Benefits: • Failed septic systems are identified and corrected through this process. • Upgrades can include increases in existing setbacks that may reduce the contamination of nearby private wells, as well as other regulatory improvements that have been passed.
	Drawbacks: • There can be significant public resistance to an inspection and upgrade program; many will have concerns about the added cost associated with a required upgrade. • Real estate agents may lobby against it, as they may perceive the program as a hindrance to selling property.	Drawbacks: • Transfer inspections and upgrades are performed lot-by-lot; there is no opportunity to look at the "big picture." • If an upgrade is seen as too expensive, the redevelopment of properties may be slowed. • It may not be possible to fully upgrade septic systems that were installed prior to regulatory changes.	Drawbacks: • Upgrading a septic system to the current design requirements may not completely eliminate cross contamination problems. • In densely developed areas, there may be limited opportunities to move a system during an upgrade.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Advanced/Alternative Onsite Wastewater Treatment Systems *Advanced or alternative wastewater treatment systems can be added to a septic system to improve the quality of effluent discharged into the ground. These treatment components are typically installed between the septic tank and the leaching facility. Many of these systems use aeration, followed by recirculation of effluent back into the anoxic septic tank, to facilitate the denitrification process. Nitrogen concentrations are usually reduced by half, with some reduction in phosphorus and biological oxygen demand.*	Benefits: • They can be used as part of an upgrade program to offset the inability to meet current setback or depth to water requirements on a previously developed marginal lot. • Many alternative technologies exist. • Performance data are readily available to evaluate alternative system reliability.	Benefits: • As the effluent receives a higher level of treatment, it is possible to reduce the leaching area requirements, and allow development on smaller, more restricted lots. • Denitrification becomes more efficient from both a financial and effluent quality perspective as systems become larger. This fact may encourage larger cluster denitrification systems, which can help to maximize development.	Benefits: • Many onsite alternative systems require regular maintenance by a qualified contractor, ensuring that a malfunctioning or failed septic system will be detected and repaired. • They can reduce cumulative water quality impacts. • Onsite alternative systems can reduce nitrogen and possibly phosphorus concentrations in groundwater, protecting surface waters from nutrient enrichment.
	Drawbacks: • The advanced treatment components increase construction costs by about $5,000 (USD) to $10,000 (USD) and also require yearly O&M. • Performance of the system is directly related to the extent of system oversight and maintenance. • There may be public resistance to technologies they do not understand.	Drawbacks: • If used in new construction, alternative onsite systems may enable development on lots that were previously undevelopable. This may not be desired. • Due to the wide variety of technologies, it can be difficult to develop a standard, codified approach to alternative septic system installation.	Drawbacks: • The level of treatment is often not enough to reduce nitrogen concentrations below the drinking water quality standard. • Most advanced treatment components added to residential septic systems do not disinfect the wastewater effluent.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Shared Septic Systems *Adjacent properties can utilize a shared septic system to discharge wastewater, eliminating the need for a system on each individual lot. This approach can be used in areas where septic systems are being upgraded, and there are space constraints on some lots, but not on others. The shared system can be a standard system, or could include components to provide advanced treatment. For this report a shared system is defined as serving no more than five separate residences.*	Benefits: • Shared septic systems can be used in new development or to upgrade existing properties. • This approach provides greater flexibility in the siting of services on small lots, especially if groundwater flow conditions are considered as the system is designed. • They may reduce the need for centralized sewer.	Benefits: • Properly siting the system in conjunction with hydrogeologic data may lead to increased land use. • It becomes easier to implement protective zoning measures, such as WHPAs, when the number of septic systems within an area is reduced, especially if the shared disposal area is outside of the WHPA. Shared systems can be used to foster Traditional Neighborhood Designs with disposal beds sited beneath common areas.	Benefits: • A shared system can be designed to avoid cross contamination conflicts with onsite private wells. • The implementation documents provide for maintenance, inspections and funding for upgrades as needed. • Shared systems can be sited so that effluent is discharged as far as possible from sensitive environmental receptors.
	Drawbacks: • The ownership of the septic system and associated sewer lines needs to be established in a manner so that all parties can rely on the system. • A mechanism is needed to provide long-term funding to maintain the system into the future. • A shared system may be more expensive. • A structure for system maintenance needs to be worked out in advance of construction.	Drawbacks: • Shared systems may allow construction on individual lots that may not otherwise be developable; this could be an issue for marginal lots in more rural areas. • Careful consideration of the equity of community land for private property improvements is required.	Drawbacks: • Depending on the technology used, shared septic systems do not necessarily reduce contaminant loadings to the groundwater. • If shared systems increase the amount of land that is developed, open space and habitat will be lost.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Centralized Sewer *Centralized wastewater can offer many treatment advantages over standard septic system treatment of wastewater.*	Benefits: • There are many firms specializing in designing and installing centralized services. • There are many centralized services in use throughout the world, enabling many options to be explored. • There are many "off the shelf" solutions; no technological barrier needs to be overcome. • Centralized systems are readily understood by the public at large.	Benefits: • Centralized infrastructure removes most limiting factors governing development (based on water and wastewater issues). • It is much easier to establish zoning districts. • Wastewater disposal areas can be located outside of densely populated areas, hopefully away from the drinking water source.	Benefits: • Centralized wastewater systems usually offer the highest levels of water quality in wastewater effluent. • The highly regulated nature of centralized wastewater systems ensures the highest level of protection for public health and the environment. • Regulation of these systems is such that any deviations in the high levels of water quality are caught and corrected early.
	Drawbacks: • Centralized services are usually expensive. • The construction of centralized services in an existing community can be quite disruptive to the ground surface, traffic patterns and daily activities. • They require long-term maintenance. • Usually a separate district and department must be established to levy user fees and to collect them.	Drawbacks: • It can become difficult to manage growth within the sewer district, as wastewater disposal is no longer perceived as a limiting factor. • Many undevelopable lots will become developable. • Open space areas previously thought to be undevelopable may be proposed for development by their owners.	Drawbacks: • Water quality impacts to groundwater and surface water from wastewater disposal need to be evaluated due to the large volume of wastewater discharged at one point.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Prioritize Communities for Central/Communal Services based on Community Amenities and Proximity to Sensitive Environmental Resources *It may be more prudent to target certain communities for central sewer service. Targeting those communities for central servicing allows residents and city planners to take into account both where the majority of public buildings and facilities are located and where sensitive environmental resources are located in relation to the community. Selection of the areas to support with centralized services could be based on the presence of existing or proposed community amenities that provide additional opportunities to support greater development. These communities are more likely to develop the economic strength to support centralized services over time.*	Benefits: • Selection of appropriate sites for centralized treatment can prioritize available infrastructure funding. • Prioritization can also be used to strengthen the communities most likely to grow and thrive.	Benefits: • Growth can be targeted to the most viable communities from an economic or environmental protection standpoint. • Growth can be controlled more easily in non-prioritized communities. • The approach can be used as a platform for more comprehensive planning (transportation, economic development, etc.).	Benefits: • Prioritized communities would receive the most protective wastewater systems, allowing for safe growth. • Many existing public health and environmental problems in prioritized communities will probably be solved via central servicing. • Using central sewer will avoid cross contamination problems.
	Drawbacks: • A very clear, understandable, and objective set of engineering prioritization parameters would need to be developed. • Prioritization process could be politically difficult. Areas with high levels of amenities may be limited by environmental constraints.	Drawbacks: • Land areas large enough to support a community leaching facility still need to be analyzed in terms of both current and expected future development levels. • Non-prioritized communities may stagnate or lose residents to the better serviced communities. • A very clear, understandable, and objective set of engineering prioritization parameters would need to be developed.	Drawbacks: • Prioritization does not solve potential public health problems (such as cross contamination) in non-prioritized communities. • Prioritization does not solve environmental contamination in non-prioritized communities.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Regulate Septic System Density Based on a Carrying Capacity Approach *Regulation of land uses within a WHPA or sensitive watershed areas can be conducted according to a carrying capacity approach. For example, the number of septic systems allowed within a WHPA can be limited to that which will keep the average nitrogen concentrations in groundwater below a 5 mg/L planning standard. The carrying capacity approach is also applicable for management of phosphorus near surface water systems. The carrying capacity of a WHPA or sensitive watershed area should consider impacts from sewage disposal as well as those from agricultural fertilizers, lawn fertilizers, road runoff and atmospheric deposition.*	Benefits: • Determines the level of development that can be supported within a WHPA based on science. • Drinking water protection can be achieved without additional wastewater treatment if appropriate density is selected.	Benefits: • Growth within a WHPA can be much more easily controlled if a carrying capacity approach is used. • The approach does not ban development, making it resistant to challenges from opponents. • Identifies opportunities for siting nutrient sources outside the WHPA and may encourage greater development. • Reduces the potential for nutrient trading to achieve compliance with cumulative loading limit (see next technique).	Benefits: • The carrying capacity approach is arguably the most protective for a public water supply in terms of nitrogen loading within a WHPA. • It is also possibly the best approach for protecting surface water resources in the WHPA from too great of an input of nutrients such as phosphorus. • It will serve to educate the public regarding those activities, which are harmful to a drinking water supply, including onsite septic systems.
	Drawbacks: • May be very difficult to implement politically. • An extensive public education campaign may be necessary to win acceptance.	Drawbacks: • Depending on the nutrient loading restrictions, some developable lots under existing zoning may become restricted in their use or undevelopable after WHPA zoning restrictions are put in place. • "Nitrogen rights" battles could arise between developers and homeowners. • The use of innovative technologies can obfuscate the concept of carrying capacity.	Drawbacks: • The carrying capacity approach does not take into account pathogens or hazardous materials. • Does not solve public health issues associated with septic system failures.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Nutrient Trading *Land use zoning controls can designate areas that are sensitive to nutrient inputs (such as a WHPA), and require the use of an onsite wastewater treatment technology that reduces nutrients. If the developer does not wish to install onsite septic systems that reduce nutrients, he or she would "buy" nutrient credits from the community on a per kilogram basis. These funds from the developer can then be placed in a septic system upgrade fund so that as pre-existing systems in the nutrient sensitive area fail, the community has the funds to pay for the difference between a standard onsite septic system and one which comes equipped with nutrient reducing technology.*	Benefits: • This system is easy to implement in that only a cost per kilogram of the nutrient of concern needs to be determined. • It offers a choice to the developer and the homeowner alike. • Technologies for nutrient removal are readily available.	Benefits: • Assists in achieving planning goals for nutrient loading. • May allow for denser development in non-nutrient sensitive areas. • It can improve existing nutrient problems. • Reduces "taking" challenges by providing an additional technique to develop what may be marginal property.	Benefits: • Helps to reduce nutrient levels that may threaten drinking water supplies. • Helps to reduce nutrient levels that may threaten sensitive environmental receptors such as wetlands, ponds, streams and rivers.
	Drawbacks: • May require some changes in regulatory structure to be able to collect the fee. • The community will have to establish and maintain the septic upgrade account. • Where the level of funding is less than what would be required to retrofit existing failed systems, the municipal authorities will have to develop an equitable approach.	Drawbacks: • May make previously undevelopable areas accessible to development. • Timeline of mitigation improvements may not match impacts to resources.	Drawbacks: • Does not provide protection to drinking water supplies or sensitive environmental receptors from pathogens. • Does not provide protection to drinking water supplies or sensitive environmental receptors from systems that may fail. • Future improvements funded by new development do not directly resolve current health threats.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Integrate Water and Wastewater Planning with Stormwater Management to Create Hydrologically Balanced Watersheds *The planning for new centralized water and sewer systems should consider how the transfer of water and wastewater between watersheds and sub-watersheds can upset local water balances that support drinking water wells, wetlands, rivers, lakes and the wildlife habitat associated with these systems. The most significant concern can be the discharge of wastewater outside the watershed from which the potable water was initially withdrawn. Centralized infrastructure planning can consider these issues and mitigating measures can be developed before a problem occurs. Management of stormwater, including appropriate infiltration techniques where feasible, can help maintain local hydrologic balances.*	Benefits: • Allows the design for water, wastewater and stormwater services to incorporate the "big picture" from the start, minimizing retro-fittings and re-routings of infrastructure later. • Proper planning may minimize need for complex wastewater or drinking water treatment facilities.	Benefits: • This is an integrated, watershed-based planning approach that will enhance "smart growth" efforts. • The approach takes into account all aspects of water management within a watershed and village, and will allow the best balance to be struck between human needs and watershed resources.	Benefits: • It will greatly aid in the protection of public health, as the approach is holistic. • It will help to protect the environment by not upsetting the natural hydrologic balance that is already in place.
	Drawbacks: • May be difficult to design and implement depending on the level of services and infrastructure already in existence within the community. • May become costly as more extensive planning is needed up front.	Drawbacks: • This approach will require more effort and money as it is holistic and many factors will need to be considered. It is "systems thinking." • It will require extensive public education and involvement, because "smart growth" is a newer planning concept.	Drawbacks: • May not fully protect public health, especially if only onsite septic systems and wells are implemented in the final plan. • Opportunities for wastewater reuse as part of an integrated plan must be carefully evaluated to minimize risk from exposure.

Matrix of Wastewater Management Approaches/Strategies

The Concept	Engineering/Implementation Perspective	Land Use Planning Perspective	Public Health/ Environmental Protection Perspective
Consider Wastewater Reuse to Minimize Impacts from Wastewater Disposal *Treated wastewater effluent does not have to be discharged to the ground, or to surface water. It can be reused for irrigation of golf courses or other common areas, or as a source of water for toilet flushing or heating/cooling operations in larger buildings. Reuse of treated wastewater effluent reduces the need for discharge of effluent to environmentally sensitive areas.*	Benefits: • May be able to design smaller wastewater disposal fields due to water reuse, thereby saving on land acquisition costs. • Will greatly enhance outdoor water conservation efforts if treated water is reused for irrigation purposes, fulfilling integrated water management goals.	Benefits: • Water reuse may make it easier to create and maintain recreational resources such as public golf courses and playing fields, as a source of irrigation water can be fairly readily provided. • Water reuse may make it easier to maintain agricultural fields as a source of irrigation water can be fairly readily provided. Less land area may need to be devoted to the construction of leaching facilities.	Benefits: • Reuse of water means that less water needs to be drawn from the aquifer, preserving the water in the aquifer for future drinking water use. • It minimizes the depletion of an important environmental resource, and will help to maintain the original hydrologic balance within the watershed as much as possible. • May minimize impacts to wetlands and other surface water resources. Can reduce fertilization requirements for irrigated areas.
	Drawbacks: • A high level of water treatment is needed (especially disinfection), making wastewater facilities more expensive to construct and maintain. • There may be a need for backup disposal facilities, which further affect the cost of this technique. • The public perception of reused wastewater can be very negative, and a public education outreach program will be needed. If regulations are not already in place governing water reuse and setting water reuse treatment level standards, they may have to be developed.	Drawbacks: • Wastewater reuse will not necessarily allow denser development to occur in a community. (Unless development is restricted by available land for wastewater disposal). The reuse of wastewater will need to be accounted for in a carrying capacity approach.	Drawbacks: • An undetected failure in the treatment system may expose the public to direct contact with un-treated or partially treated sewage effluent. An undetected failure in the treatment system may also create contaminated runoff that may find its way into wetlands, ponds, lakes, streams and rivers and the ocean.

4.8 Opportunities to Implement Alternative Wastewater Strategies

As mentioned earlier, the Hawaii DOH does allow the use of some alternative septic system technologies such as composting toilets and constructed wetlands. However, a number of the technologies described in this Chapter can only be used following approval by DOH as an experimental system. This process may discourage the use of systems that can provide for nutrient, and possibly, pathogen removal.

Other states in the country have developed a process of pre-approving alternative technologies to foster their use in appropriate applications. For example, the State of Massachusetts has an extensive list of approved technologies for use in on-site septic system designs. This allows developers and health officials to select and use a technology that can provide for a higher quality effluent. It also allows them to obtain credits, or waivers, in the design of systems, such as for an increase in flow in nitrogen sensitive areas (using a system that removes nitrogen), a reduction in leaching field size, or a reduction in the depth to groundwater. Many of these credits also facilitate the use of alternative technologies in the upgrade of existing systems in dense communities located in sensitive areas.

The list of Massachusetts approved technologies is provided below. This list is shown as an example because of the extensive number of technologies that have been approved. Each approval is provided by the state Department of Environmental Protection in a letter that provides the design and operation and maintenance requirements for the technology. Further information on the approval process and the alternative technologies is provided at www.mass.gov/dep/water/wastewat.htm. Oregon's Department of Environmental Quality has a similar approval process, although the number of approved technologies are not as extensive www.deq.state.or.us/wq/onsite/aattechnology.htm .

Hawaii could consider a similar pre-approval process to facilitate the use of septic system technologies that could improve groundwater and surface water quality in sensitive watersheds. This could potentially encourage the Counties to require the use of these systems in new construction, and could aid in the upgrade of existing systems in sensitive areas.

List of Approved Alternative Technologies
Massachusetts Department of Environmental Protection

Certified for General Use
Click here for approval letters and O&M checklists for all technologies certified for general use.

Technology	Model(s)	Company	Technology Description	Approved Use
Composting Toilets	Compliant with Title 5	Generic	Composting Toilet	Composting toilets as described in Title 5 (310 CMR 15.289 (3)(b))
Biolet	XL Composting Toilet	Biolet USA, Inc. 150 East State Street Newcomerstown, OH 43832	Composting Toilet	Equivalent to composting toilets as described in Title 5 (310 CMR 15.289 (3)(b))
Sun-Mar	Compliant with Title 5	Sun-Mar Corp. 5370 South Service Rd. Burlington, ON, L7L 5L1	Composting Toilet	Equivalent to composting toilets as described in Title 5 (310 CMR 15.289 (3)(b))
Recirculating Sand Filter	Compliant with Title 5	Generic	Sand Filter	BOD_5 and TSS removal Nitrogen reduction
RUCK	Systems less than 2000 gpd	Innovative RUCK Systems, Inc. 200 Main Street Falmouth, MA 02540	Filter	Nitrogen Reduction Equivalent to conventional Title 5 system
FRALO SEPTECH Poly Tanks	ST-1060, ST-1250 and ST-1500	FRALO Plastech Manufacturing, LLC One General Motors Drive Syracuse, NY 13206	Polyethylene septic tank	Equivalent to conventional septic tank
Advantex	Advantex AX20	Orenco Systems, Inc. 814 Airways Avenue Sutherlin, OR 97479	Textile filter	Equivalent to conventional Title 5 system
SeptiTech Treatment System	400, 550, 750, 1200, 1500, 3000H	SeptiTech, Inc. 220 Lewiston Road Gray, ME 04039	Trickling Filter	
Intermittent Sand Filter by Orenco Systems, Inc.	Low-Rate	Saneco, Inc. Box 9B 65 Eastern Avenue Essex, MA 01929	Sand Filter	
Bioclere	16, 22, 24, 30, and 36 series	Aquapoint 241 Duchaine Blvd. New Bedford, MA 02745	Trickling Filter	
Cromaglass WWT Systems	CA-5, CA-12, CA-25, CA-30, CA-50, CA-60, CA-100, CA-120, and CA-150	Cromaglass Corporation P.O. Box 3215 2902 N. Reach Road Williamsport, PA 17701	Sequencing Batch Reactor	
JET Aerobic Wastewater Treatment	JET-500, JET-750, JET-1250, JET-1500	Clearwater Recovery 175 Spring Street Rockland, MA 02370	Aerobic Treatment Unit	
FAST	MicroFAST, High Strength FAST, and NitriFAST	Bio-Microbics, Inc. 8450 Cole Parkway Shawnee, KS 66227	Aerobic Treatment Unit	
FAST	Modular FAST	Smith & Loveless,	Aerobic	

Certified for General Use

Click here for approval letters and O&M checklists for all technologies certified for general use.

Technology	Model(s)	Company	Technology Description	Approved Use
		Inc. 14040 Santa Fe Trail Drive Lenexa, KS 66215	Treatment Unit	
Norweco	Singulair 960 and 960 DN	Siegmund Environmental Services, Inc. 49 Pavilion Avenue Providence, RI 02905	Aerobic Treatment Unit	
Amphidrome	Amphidrome Process	F.R. Mahony & Associates, Inc. 131 Weymouth Street Rockland, MA 02370	Submerged Attached-Growth Sequencing Bioreactor	
Waterloo	Biofilter	Waterloo Biofilter System, Inc. 143 Dennis Street Rockwood, ONT, N0B 2K0	Trickling Filter	
Eljen Xpandable Chamber	XP1607 through XP 3614	Eljen Corporation 125 McKee Street East Hartford, CT 06108	Alternative SAS	Alternative SAS in trench, bed, or gallery configurations
EZ Flow	EZ1202V, EZ1203T, EZ1203H, EZ1402V, EZ1203 Bed, EZ1203 Mound	Ring Industrial Group/EZ Flow 65 Industrial Park Road Oakland, TN 38060	Alternative SAS	
Hancor Enviro Chambers	Standard Capacity, High Capacity, and Narrow	Hancor, Inc 401 Olive Street Findlay, OS 45840	Alternative SAS	
BioDiffuser Chambers	Biodiffuser 14 inch and 16 inch High Capacity, 11 inch Standard and Bio 2 and Bio 3 Biodiffusers	Advanced Drainage Systems, Inc. 4640 Trueman Boulevard Hilliard, OH 43026	Alternative SAS	Alternative SAS in trench, bed, or gallery configurations with 40% reduction in size with effluent loading rates specified in Title 5 (310 CMR 15.242).
Cultec Chambers	EZ-24, Recharger 280 and 400	Cultec, Inc. 878 Federal Road Brookfield, CT 06804	Alternative SAS	
Cultec Chambers	Contactor 75, 100, 125; Recharger 180 and 330			
Cultec Chambers	Contactor Field Drain C1, C2, C3, and C4			
Infiltrator	High Capacity	Infiltrator Systems,	Alternative SAS	

Certified for General Use Click here for approval letters and O&M checklists for all technologies certified for general use.				
Technology	**Model(s)**	**Company**	**Technology Description**	**Approved Use**
Chambers	Chamber, Standard Chamber, Infiltrator 3050 (Storm Tech SC-740) and Equalizer 24 and 36	Inc. P.O. Box 768 6 Business Park Road Old Saybrook, CT 06475		
Eljen In-Drain Systems	Type B43 and A42	Eljen Corporation 125 McKee Street East Hartford, CT 06108	Alternative SAS	
Enviro-Septic Leaching System	Enviro-Septic	Presby Enviromental Inc. Route 117, PO Box 617 Sugar Hill, NH 03586	Alternative SAS *	* Bed only

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Approved for Piloting
Click here for approval letters and O&M checklists for all technologies approved for piloting use.

Technology	Model(s)	Company	Technology Description	Approved Use
Omni Recirculating Sand Filter System	RSF System	OMNI Environmental Systems, Inc. P.O. Box 128/465 East Falmouth Hwy Falmouth, MA 02536	Recirculating Sand Filter	BOD_5 and TSS removal Nitrogen reduction
Cromaglass WWT System	CA-5D, CA-12D, CA-25D, CA-30D, CA-50D, CA-60D, CA-100D, CA-120D, and CA-150D	Cromaglass Corporation P.O. Box 3215 2902 N. Reach Road Williamsport, PA 17701	Sequencing Batch Reactor	
Amphidrome Process	Amphidrome Process	F.R. Mahony & Associates, Inc. 131 Weymouth Street Rockland, MA 02370	Submerged Attached-Growth Sequencing Bioreactor	
Norweco	Singulair 960 DN	Siegmund Environmental Services, Inc. 49 Pavilion Avenue Providence, RI 02905	Aerobic Treatment Unit	
Nitrex	Nitrex Filters and Nitrex Plus Filters	Lombardo Associates, Inc. 49 Edge Hill Road Newton, MA 02467-1170	Filter with nitrate-reactive media	
RID	RID Phosphorus Removal System	Lombardo Associates, Inc. 49 Edge Hill Road Newton, MA 02467-1170	Upflow filter	Phosphorus removal
Waterloo	Biofilter	Waterloo Biofilter System, Inc. 143 Dennis Street Rockwood, ONT, N0B 2K0	Trickling Filter	Increased loading rates and reduced separation to groundwater
SeptiTech Treatment Systems	400N, 550N, 750N, 1200N, 1500N, 3000N, SeptiTech Engineered Systems	SeptiTech, Inc. 220 Lewiston Road Gray, ME 04039	Enhanced recirculating biological trickling filter	BOD_5 and TSS removal & Nitrogen reduction
RUCK	CFT System	North Coast Technologies, LLC 200 Main Street, Suite 201 Falmouth, MA 02540	Aerobic RUCK filter	Nitrogen reduction
OAR	OAR System	Environmental Operating Solutions,	Aerobic reactor with Bio-	

Approved for Piloting Click here for approval letters and O&M checklists for all technologies approved for piloting use.				
Technology	**Model(s)**	**Company**	**Technology Description**	**Approved Use**
		Inc. 230 Jones Street Falmouth, MA 02540	augmentation	

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Approved for Remedial Use Click here for approval letters and O&M checklists for all technologies approved for remedial use.				
Technology	**Model(s)**	**Company**	**Technology Description**	**Approved Use**
White Knight Inoculator / Generator Alternative Treatment System	Bacterial Augmentation and Aeration System	Knight Treatment Systems 281 County Route 51A Oswego, NY 13126	Bio-augmentation	Renovation of failed SAS
Piranaco Alternative Treatement System	Bacterial Augmentation and Aeration System	Piranaco 1875 Joy Road Occidental, CA 95465		
Geoflow Subsurface Drip Wastewater Disposal System	Drip Irrigation System	Geoflow Inc. 500 Tamal Plaza, Suite 506 Corte Madera, CA 94925	Alternative SAS	Alternative SAS trench-drip irrigation
Perc-Rite Subsurface Drip Wastewater Disposal System	Drip Irrigation System	American Manufacturing Co. Inc. P.O. Box 549 Manassas, VA 20108-0549	Alternative SAS	Alternative SAS trench-drip irrigation
Composting Toilets	Compliant with Title 5	Generic	Composting Toilet	Composting toilets as described in Title 5 (310 CMR 15.289 (3)(b))
Recirculating Sand Filters	Compliant with Title 5	Generic	Sand Filter	BOD_5 and TSS removal
The Clean Solution Alternative	Models: 250, 250 PT, 250ST3, 250ST4, 600, 1000, 1750, 2500, 3100 and 10000	Wastewater Alternatives of New England, LLC 27 Kensington Road Hampton Falls, NH 03844	Submerged media biological treatment	
Puraflo	Peat Fiber Biofilter	Bord na Mona Environmental Products U.S. Inc. 4106 Bernau	Peat Filter	

Approved for Remedial Use Click here for approval letters and O&M checklists for all technologies approved for remedial use.				
Technology	**Model(s)**	**Company**	**Technology Description**	**Approved Use**
White Knight Inoculator / Generator Alternative Treatment System	Bacterial Augmentation and Aeration System	Knight Treatment Systems 281 County Route 51A Oswego, NY 13126	Bio-augmentation	Renovation of failed SAS
Piranaco Alternative Treatement System	Bacterial Augmentation and Aeration System	Piranaco 1875 Joy Road Occidental, CA 95465		
Geoflow Subsurface Drip Wastewater Disposal System	Drip Irrigation System	Geoflow Inc. 500 Tamal Plaza, Suite 506 Corte Madera, CA 94925	Alternative SAS	Alternative SAS trench-drip irrigation
		Avenue Greensboro, NC 27407		
Jet Home Aerobic Wastewater Systems	J-500, J-750, J-1000, J-1250, and J-1500	Clearwater Recovery (Stephen B. Nelson) 175 Spring Street Rockland, MA 02370	Aerobic treatment system	
Amphidrome	Amphidrome Process	F.R. Mahony & Associates, Inc. 131 Weymouth Street Rockland, MA 02370	Submerged Attached-Growth Sequencing Bioreactor	
Orenco Intermittent Sand Filter	Low-Rate Filter	Saneco, Inc. Box 9B 65 Eastern Avenue Essex, MA 01929	Sand Filter	
Norweco	Singulair Systems 960N, 960/750, 960/1000, 960/1250, and 960/1500	NORWECO, Inc. 220 Republic Street Norwalk, OH 44857	Aerobic treatment	
Waterloo Biofilter	Biofilter	Waterloo Biofilter System, Inc. 143 Dennis Street Rockwood, ONT, N0B 2K0	Trickling Filter	

Approved for Remedial Use Click here for approval letters and O&M checklists for all technologies approved for remedial use.				
Technology	**Model(s)**	**Company**	**Technology Description**	**Approved Use**
White Knight Inoculator / Generator Alternative Treatment System	Bacterial Augmentation and Aeration System	Knight Treatment Systems 281 County Route 51A Oswego, NY 13126	Bio-augmentation	Renovation of failed SAS
Piranaco Alternative Treatement System	Bacterial Augmentation and Aeration System	Piranaco 1875 Joy Road Occidental, CA 95465		
Geoflow Subsurface Drip Wastewater Disposal System	Drip Irrigation System	Geoflow Inc. 500 Tamal Plaza, Suite 506 Corte Madera, CA 94925	Alternative SAS	Alternative SAS trench-drip irrigation
AdvanTex Treatment Systems	AX-15, AX-20 and AX-100	Orenco Systems, Inc. 814 Airways Avenue Sutherlin, OR 97479	Textile media aerobic treatment	
FAST	Modular FAST	Smith & Loveless, Inc. 14040 Santa Fe Trail Drive Lenexa, KS 66215	Aerobic Treatment Unit	
FAST	MicroFAST, High Strength FAST, and NitriFAST	Bio-Microbics, Inc. 8450 Cole Parkway Shawnee, KS 66227	Aerobic Treatment Unit	
SeptiTech Treatment Systems	300, 400, 550, 750, 1200 3000, and SeptiTech Engineered Systems	SeptiTech, Inc. 220 Lewiston Road Gray, ME 04039	Aerobic Treatment unit	
Cromaglass Wastewater Treatment System	CA-5, CA-12, CA-15, CA-25, CA-30, CA-50, CA-60, CA-100, CA-120, CA-150	Cromaglass Corporation P.O. Box 3215 2902 N. Reach Road Williamsport, PA 17701	Sequencing Batch Reactor	
Bioclere	16, 22, 24, and 30 series	Aquapoint 241 Duchaine Blvd. New Bedford, MA	Trickling Filter	

Approved for Remedial Use Click here for approval letters and O&M checklists for all technologies approved for remedial use.				
Technology	**Model(s)**	**Company**	**Technology Description**	**Approved Use**
White Knight Inoculator / Generator Alternative Treatment System	Bacterial Augmentation and Aeration System	Knight Treatment Systems 281 County Route 51A Oswego, NY 13126	Bio-augmentation	Renovation of failed SAS
Piranaco Alternative Treatement System	Bacterial Augmentation and Aeration System	Piranaco 1875 Joy Road Occidental, CA 95465		
Geoflow Subsurface Drip Wastewater Disposal System	Drip Irrigation System	Geoflow Inc. 500 Tamal Plaza, Suite 506 Corte Madera, CA 94925	Alternative SAS	Alternative SAS trench-drip irrigation
		02745		
Jet	J-335 Tertiary Sand Filter	Clearwater Recovery (Stephen B. Nelson) 175 Spring Street Rockland, MA 02370	Sand filter	NA
Enviro-Septic	Enviro-Septic System	Presby Enviromental Inc. Route 117, PO Box 617 Sugar Hill, NH 03586	Alternative SAS	Alternative SAS in bed configurations with 40% reduction in size with effluent loading rates specified in Title 5 (310 CMR 15.242).
Eljen In-Drain Systems	Type B43 and A42	Eljen Corporation 125 McKee Street East Hartford, CT 06108	Alternative SAS	Alternative SAS in trench, bed, or gallery configurations with 40% reduction in size with effluent loading rates specified in Title 5 (310 CMR 15.242).

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I/A Technologies with Nitrogen Reduction Credit

A number of the technologies listed above have received nitrogen reduction credit as part of their technology approvals:

General Use Certification

Recirculating Sand Filters
RUCK

Provisional Use Approvals

Advantex
Amphidrome
Bioclere
MicroFAST, High Strength FAST, NitriFAST, and Modular FAST
Waterloo Biofilter

Piloting Use Approvals

Amphidrome Process
Cromaglass WWT System
Nitrex-Nitrex Plus
Norweco Singulair
OAR
OMNI Recirculating Sand Filter System
RUCK CFT
SeptiTech

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Technologies Under Review by MassDEP			
Technology	**Company**	**Technology Description**	**Proposed MassDEP Approval**
WAI BioCon	Wastewater Alternatives of NE, Inc.	Aerated submerged media biological contractor	Remedial
WAI BioCon	Wastewater Alternatives of NE, Inc.	Aerated submerged media biological contractor	General
GeoFlow Drip	GeoFlow	Drip Irrigation	General Use
MBR	Bio-Microbics	Membrane Reactor	Piloting
Singulair	Seigmund Environmental	Aerated Biological Contractor	Provisional

4.9 Case Studies

One of the purposes of this workbook is to demonstrate that there can be solutions to even the most challenging wastewater servicing problems. The following case studies illustrate how other communities have addressed serious servicing issues. While not all of the case studies may be applicable to Hawaii, they do serve to confirm that through a combination of determination and innovation (and not necessarily more money), most problems can be addressed.

Many of the case studies are from island communities, like Hawaii. Such communities represent the extreme conditions of a limited resource base such as fresh water. When faced with growth pressures, island communities require some of the most innovative wastewater servicing solutions.

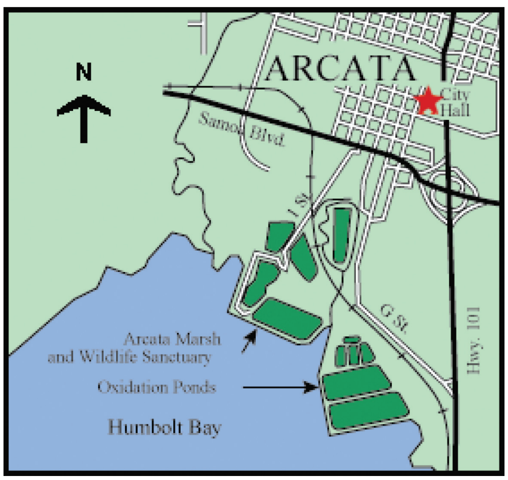
A Natural System for Wastewater Reclamation and Resource Enhancement
Arcata, California

Community Information

Status: City
Population: 17,000

Program Description

The constructed wetland system is the cornerstone of Arcata's urban watershed renovation program. This program includes major urban stream restoration, log pond conversion to a swamp habitat, pocket wetlands on critical reaches of urban streams, and an anadramous wastewater aquaculture program to restore critical commercial, recreational, and ecological important populations. The Arcata project is a demonstration of wastewater reuse, ecological restoration, and reuse of industrial, agricultural and public service land.



Arcata Site Plan

Situated in the heart of the redwood country and along the rocky shores of the Pacific Northcoast, the City of Arcata is located on the northeast shore of Humboldt Bay in Northern California, 280 miles north of San Francisco. Arcata, with a population of approximately 15,000, is a diverse community whose resourcefulness and integrity has demonstrated that a constructed wetland system can be a cost efficient and environmentally sound wastewater treatment solution. In addition to effectively fulfilling wastewater treatment needs, Arcata's innovative wetland system has provided an inspiring bay view window to the benefits of integrated wetland enhancement and wastewater treatment.

What is the Arcata Marsh and Wildlife Sanctuary?

Arcata is a small town located on the northeastern side of Humboldt Bay, about 280 miles north of San Francisco. Humboldt Bay is a focal point where timber resources and marine resources cross paths as they struggle to sustain Humboldt County's economy. Resource management is a practice that receives high priority and expert advice in this scenic niche of the Pacific North coast. Arcata, with a population of approximately 15,000, is a diverse community whose resourcefulness and integrity has served to lead the city down a successful path marked by innovative decisions and maintained by pride. So, when the city faced making a change in their wastewater treatment methods, they demonstrated that a constructed wetland system can be a cost efficient and environmentally sound wastewater treatment solution. In addition to effectively fulfilling wastewater treatment needs, Arcata's innovative wetland system has provided an inspiring bay view window to the benefits of integrated wetland enhancement and wastewater treatment.

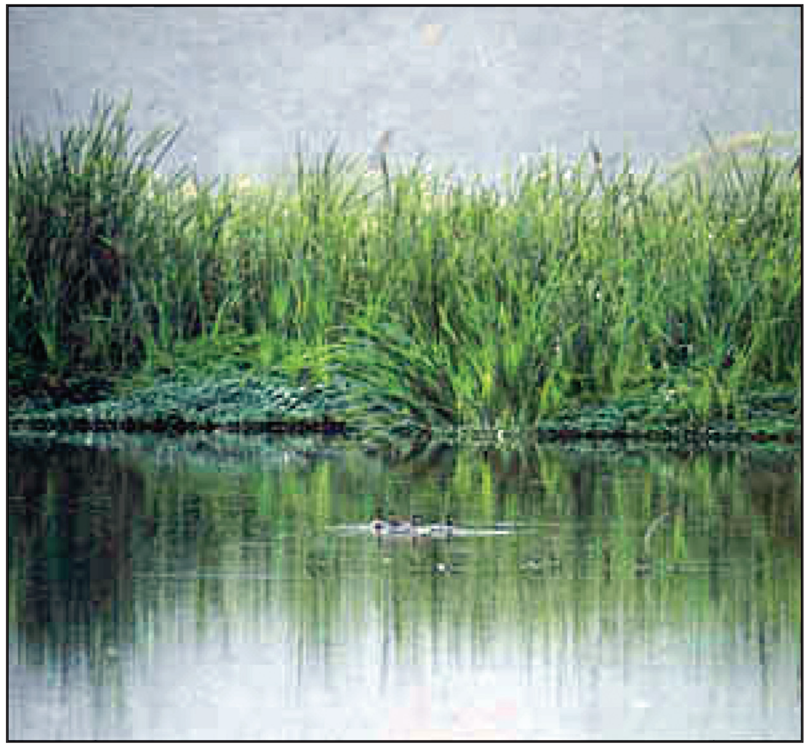
How did the project evolve?

Arcata established its innovative treatment system as a result of extensive community involvement and a series of political events. In the early 1970's, Arcata's active wastewater treatment plant discharged unchlorinated primary effluent into Humboldt Bay. In 1974 the State of California enacted a policy which prohibited discharge of wastewater into bays and estuaries unless enhancement of the receiving water was proven. In response to this policy the local Humboldt Bay Wastewater Authority proposed the construction of a state sponsored regional wastewater treatment plant that would serve all the communities in the Humboldt Bay vicinity. The plant was to have large interceptors around the perimeter of the bay with a major line crossing under the bay in the region of active navigation. The proposed treatment facility was energy intensive, with significant operational requirements. Effluent from the proposed plant was to be released offshore into an area of shifting sea bottom and heavy seas during winter storms. As the scale of the regional treatment plant grew, the costs and difficulties of incorporating other communities became apparent.

Recognizing the constraints of the local environment and criteria for wastewater treatment, the City of Arcata began exploring the design of a decentralized system, which employed constructed wetlands. Wastewater aquaculture projects at the City of Arcata started as early as 1969 and had been successful in raising juvenile Pacific Salmon and Trout in mixtures of partially treated wastewater and seawater. This project demonstrated that wastewater was a "resource" that could be reused and not simply to be viewed as a disposal problem. With this philosophy a city Task Force on Wastewater Treatment determined that the natural processes of a constructed wetland system could offer the city an effective and efficient wastewater treatment system. From 1979 to 1982 the city, and associated proponents of alternative wastewater treatment, experimented with partially treated wastewater and the natural processes of wetland ecosystems. These experiments demonstrated that constructed freshwater wetlands could be utilized to treat Arcata's wastewater and at the same time enhance the biological productivity of the wetland environment into which treated wastewater was discharged. The Task Force determined that a constructed wetland system was extremely cost effective. Moreover, a successful system offers the city a vital wetland ecosystem that could be used for the rearing of salmon and steelhead as well as offer the community a unique site for recreation and education.

With the aid of the Arcata City Council and political representatives in the state capital, the city received authorization in 1983 to develop the constructed wetland system and incorporate its use at the original Arcata Wastewater Treatment Plant. The wetland system that exists today was completed in 1986. Since that time the natural ability of marsh plants, soils and their associated microorganisms has successfully been utilized to meet the need for a cost-effective and environmentally sound wastewater treatment technology that meets federal and state mandated water quality requirements.

Who cares and what are the benefits?

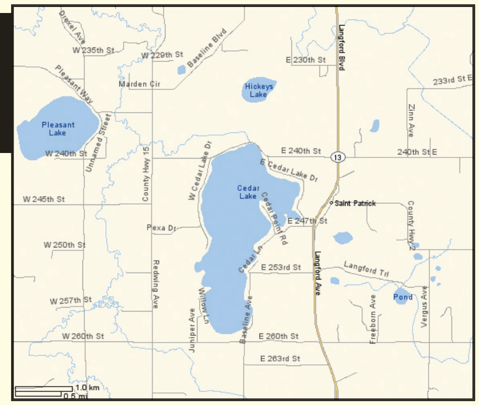


At the same time that wetland wastewater technology has been used to successfully meet water quality criteria, it has also aided in restoring a degraded urban waterfront. Prior to the installation of its wetland treatment system, the City of Arcata's waterfront was the site of an abandoned lumbermill pond, channelized sloughs, marginal pasture lands, and a closed sanitary landfill. Today, Arcata's waterfront has been transformed into 100 acres of freshwater and saltwater marshes, brackish ponds, tidal sloughs and estuaries. Because of the wetland communities and wildlife habitats that the waterfront now supports, the area in its entirety has come to be known as the Arcata Marsh and Wildlife Sanctuary (AMWS.) The AMWS's three freshwater wetlands are Gearheart, Allen and Hauser Marshes. They were constructed to receive treated wastewater, thereby treating the wastewater further and enhancing the receiving water at the same time. These enhancement marshes are a host of aquatic vegetation that, in association with Klopp Lake and the adjacent estuaries and ponds, have further provided an extraordinary habitat for shorebirds, waterfowl, raptors and migratory birds.

As a home or rest stop for over 200 species of birds, the AMWS has developed a reputation as one of the best birding sites along the Pacific North Coast. The Redwood Region Audubon Society uses the site on a regular basis for its weekly nature walks. For the past 10 years, docents trained by the Society have explained the role the wetlands play in attracting birds and mammals, as well a s their role in managing the water quality of Humboldt Bay. The beauty and uniqueness of the AMWS has served as inspiration to many artists, whose products range in form from plays and poems to photographs and paintings.

Arcata has become an international model of appropriate and successful wastewater reuse and wetland enhancement technologies. Over 150,000 people a year use the AMWS for passive recreation, bird watching, or scientific study. Visitors from around the world have come to Arcata to investigate its success in wastewater management. Students of all ages and institutions use the AMWS for scientific study. In 1987, the City of Arcata was selected by the Ford Foundation to receive an award for this wastewater wetlands project as an innovative local government project. This award included a $100,000 prize to be used to fund the establishment of the Arcata Marsh Interpretive Center. The Center focuses on the historical, biological and technical aspects of the AMWS, and attempts to meet the informational and educational demands of the wastewater treatment system.

Pressure Sewer Systems for a Small Lakeside Community Cedar Lake, Minnesota, USA



Community Information

Status: Township
Population: 2,299

Program Description

Cedar Lake Township is located in southeastern Minnesota on the shores of Cedar Lake. Like many lakeside communities in Minnesota, it is experiencing increased residential activity as former urbanites head to the country to live in their "dream" home. Many of the homes around Cedar Lake were built with on-site septic systems, systems which many urbanites are not familiar with. In 1997, many homeowners in Cedar Lake realized that their septic systems were outdated and did not meet state or county codes. In an effort to limit the pollutant load to the lake through substandard and failing septic systems, local residents were avoiding using their washing machines and sink disposals. The residents of Cedar Lake formed an association to begin to investigate their wastewater management options, and decided to install a cluster wastewater treatment system.

The chosen wastewater treatment system was a pressure sewer system tied to a regional treatment plant. Characteristics of lake area topography, such as high groundwater, rolling hills, or rocky terrain, usually make the installation of a conventional gravity system costly. A pressure sewer system may be installed for 30-50% less than a conventional system in these areas. In addition to the potential economic advantage, pressure sewer systems have much less of an impact to the surrounding area when they are installed. Because they do not rely on gravity, system piping can be laid to follow the contour of the land. In addition, trenches are not needed for installation of sewer pipe. Instead, directional drilling, a technique frequently used in the oil industry, can be used to bore horizontal holes into which the piping is laid. This drilling method leads to less disruption of the landscape. In Cedar Lake, residents wanted to avoid the disruption caused by trenching. In addition, the estimated cost of a pressure system was $3,300,000 USD, 1.2 million USD less than a conventional gravity system. These cost numbers also reflect the construction of a force main to an existing regional wastewater treatment plant.

Each home in Cedar Lake is equipped with a small grinder pump station buried in the yard. Wastewater from the home flows into the pump station where grinder blades shred the solids into a slurry. The system then collects the sewage in a "ring route" of in-ground, gravelless 25.4-cm diameter corrugated polyethylene pipe that circles the lake and leads to a larger pumping station. This larger pumping station pumps the wastewater to the New Prague Wastewater Treatment Plant for treatment and eventual disposal. This pumping station is located away from the residents homes and away from the lake.

Additional Program Description

Process for Selection: Consultant assistance
Operational Date: July, 2002
Capital Cost: \$3,300,000 capital (estimated)
Operation Cost: \$432 USD/year/household (estimated)
Management Model: Wastewater District
Legal Actions Needed: Establishment of "Cedar Lake Area Water and Sanitary Sewer District" in state legislature
Indicators of Success: Residents may now use washing machines and sink disposals again
Lessons Learned: N/A

Cost Information

Residents in the Cedar Lake Water & Sewer District are subject to regulations, connection fees, and treatment charges imposed by the City of New Prague. Each homeowner will be charged a monthly fee estimated at \$36 USD (\$432 USD per year). This fee covers the operation, maintenance and replacement costs, as well as monthly treatment fees paid to the City of New Prague.

Contact Information

Mr. Bob Brautigam
Cedar Lake Area Water and Sanitary Sewer District
952-758-2364

Related Links

http://www.bolton-menk.com/news/pdf/newsletter2-2002.pdf
http://www.ocwagis.org/Website/downloads/Decentralized/decentralized.htm
http://www.ces.purdue.edu/extmedia/AE/ID-265.pdf

Island Road Shared Septic System
Essex, Massachusetts

Community Information

Status: Town
Population: 3,267

Program Description

Island Road is a narrow, unpaved road that dead-ends at the bank of the Essex River in Essex, Massachusetts. The Town of Essex is a small town located about 55 kilometers north of Boston. There is no town sewer, and residents outside of the village center rely on private well water. The Essex River is a brackish, estuarine system heavily influenced by the tides. Four homes were located at the end of Island Road, in close proximity to the Essex River and its commercial shellfish beds. Due to contamination in the Essex River, the Town of Essex was forced by the Commonwealth of Massachusetts to inspect every septic system in Town and require homeowners to upgrade their septic systems if they were found to be failing. All four septic systems at the end of Island Road were found to be failing; however, no property owner had soil conditions such that the systems could be individually repaired on-site in accordance with state regulation.

A property owner further up Island Road, away from the River, decided to build a house on her relatively large (.4+ hectare) lot. As her lot was further from the River, soil conditions were much more suitable for installing an on-site septic system. Approached by the four homeowners on the end of Island Road, she agreed to allow them to construct a shared leaching facility on her property. As shared septic systems where still unique in Massachusetts at that point in time, the four homeowners received a $50,000 USD grant to aid in the construction of the shared septic system.

Construction of the system could not proceed until an easement had been granted to allow the four homeowners to dispose of their wastewater on the neighboring property. The Trust also developed a maintenance "Covenant" to ensure that any needed repairs to the shared system would occur and be funded by the four property owners and to ensure that the system would be inspected annually by a state-licensed inspector. The Covenant was approved by the state's Department of Environmental Protection, who also reviewed the plans for the shared system. This Covenant was recorded with the Registry of Deeds.

Additional Program Information

Capital Cost: < $100,000.00 USD
Management Model: Shared Septic System
Operation Cost: Routine maintenance (pump-outs), annual inspection fees, legal fees for maintenance of Covenant and easement
Indicators of Success: Four failed septic systems adjacent to environmentally sensitive shellfish beds have been removed and replaced with one septic system that discharges properly treated sewage away from the shellfish beds.
Lessons Learned: In a remedial situation, shared systems are typically viewed as a means of last resort as they force neighbors to rely on one another for the long term.

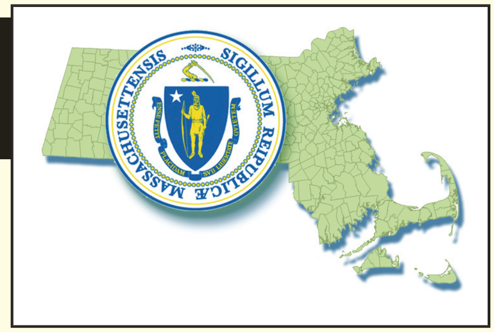
Contact Information

Brendhan Zubricki
Town Administrator, Town of Essex
(978) 768-6531

Related Links

http://www.essexma.org/
http://users.rcn.com/essexboh/home.shtml
http://www.gis.net/~ewd/page6.htm

Property Transfer Septic System Inspections
Massachusetts, USA



Community Information

Status: Commonwealth
Population: 6,349,097

Program Description

One way to ensure that a septic system is examined by a professional to determine its operational status is to require an inspection any time the title of the property is transferred to a new owner. In the United States, the State of Massachusetts currently requires time of transfer inspections in their regulations governing on-site sewage treatment and disposal. The inspection has to be performed by a state-licensed inspector using a standardized state inspection form that is submitted to both the buyer and the local health department. Transactions in Massachusetts excluded from the inspection requirement include:

- Taking a security interest in a property, including issuing a mortgage.
- Refinancing a mortgage, whether or not the identity of the lender remains the same.
- A change in the form of ownership among the same owners (such as placing a property in trust with the current owners as beneficiaries).
- Adding or deleting a spouse as an owner or beneficiary.
- The appointment of or a change in a guardian, conservator, or trustee.

Other provisions of the time of transfer regulation cover unique circumstances such as condominiums, foreclosure, inheritance, legal life estate, inter-family transfers, tax taking by government, levy of execution resulting in property conveyance, bankruptcy, and other changes in ownership such as new beneficiaries.

The regulations also provide for some exceptions to the time of transfer inspection. If an inspection has been performed up to two years prior to the time of transfer, another inspection is not needed. This can be extended up to three years prior to time of transfer with proof that the system has been pumped every year since the last inspection. If the system was newly installed within the last two years an inspection is not required. Some communities may have comprehensive septic inspection programs, approved by the state, that ensure every system in the community is inspected at least once every seven years. In these communities, time of transfer inspections are not required. The final exception to the time of transfer inspection requirement occurs when the person acquiring title has signed an enforceable agreement to upgrade the septic system or to connect to a sanitary sewer within two years following the transfer of title.

Additional Program Information

Capital Cost: N/A
Management Model: Mandatory Inspection Program
Operation Cost: $200.00 to $600.00 USD inspection fee (depends on complexity of system)
Indicators of Success: Hundreds of failed septic systems and cesspools across the state have been repaired/upgraded
Lessons Learned: Involving the real estate community was an important step for acceptance of this new regulation which took effect in 1995.

Contact Information

Massachusetts Department of Environmental Protection's Title 5 Hotline
(800) 266-1122

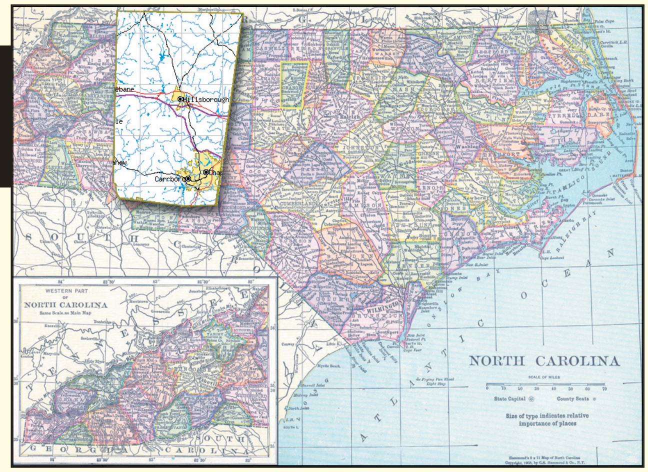
Related Links

http://www.state.ma.us/dep/brp/wwm/onsite.htm
http://www.state.ma.us/dep/brp/wwm/t5regs.htm
http://www.state.ma.us/dep/brp/files/310CMR15.PDF

Orange County
North Carolina

Community Information

Status: County
Population: 118,227



Program Description

Orange County, North Carolina, home to Hillsborough, Chapel Hill, and the University of North Carolina, created an on-site septic system management program supervised by the Orange County Health Department. This management program requires the inspection of on-site septic systems depending on their engineering "complexity." For example:

- A standard gravity-fed septic system and leachfield requires no regular inspection
- Any system using a pump must be inspected every five years by an official from the County Health Department.
- Any "pressure dosed" or low pressure pipe system must be inspected every three years by the County and every six months by a licensed contractor hired by the home owner. This contractor submits a report to the County annually.
- Any system which "pre-treats" sewage effluent, such as a sand filter or biofilter system, must be inspected annually by the County and every three months by a licensed contractor hired by the homeowner.

State law provides the County with several ways to cover the cost of these inspections, and the County currently charges the homeowner $100.00 USD at the time of each inspection. To make the current program more effective, the County is considering developing educational courses to train homeowners, inspectors, and maintenance professionals, a certification program for homeowners to teach them how to check solids levels in their tanks or help neighbors troubleshoot their systems, a technical/mechanical manual for homeowners, and even a video on home septic system maintenance. The County also hopes to require inspections of standard, gravity-fed septic systems via a mechanism such as requiring new homeowners to "re-permit" their systems when a home is purchased.

Additional Program Information

Capital Cost: N/A
Management Model: Regular Inspection Program
Operation Cost: $100.00 USD per household at time of inspection
Indicators of Success: N/A
Lessons Learned: N/A

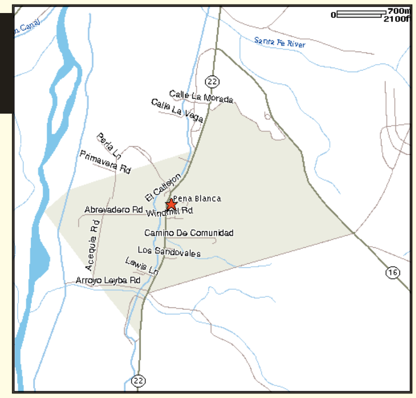
Contact Information

Jim Brown
Environmental Health Specialist
(919) 245-2360

Related Links

http://www.co.orange.nc.us/envhlth/eseptic.htm
http://www.nesc.wvu.edu/nodp/pdf/OnsiteSystem.pdf

Peña Blanca
New Mexico



Community Information

Status: Town
Population: 661

Program Description

This small community of approximately 185 homes and businesses, located approximately 40 kilometers west of Santa Fe close to the bank of the Rio Grande, faced a public health problem in 1985 when an increasing number of septic tank and cesspool failures resulted in sewage "breakout." An engineering study found that inadequate systems, high groundwater conditions and a lack of homeowner maintenance where the main causes of the problem. The Town decided to solve its wastewater problems through the replacement of individual, failed on-site systems simultaneously and the establishment of an on-site wastewater management district.

The Town organized its district under the Peña Blanca Water and Sanitation District (WSD), which has the power to levy and collect taxes, the right to issue general obligation and revenue bonds, and the right to require homeowners within the district to connect to a sewer system in the interest of public health and safety. Four on-site easements were created prior to construction of new systems: a standard easement agreement (allowed for the performance of work, access for construction and maintenance, and allows for the payment of monthly fees), a no work easement agreement (for functioning systems not requiring replacement, allows for the payment of monthly fees), a neighboring disposal system easement (used where cluster systems were installed, it includes all elements of the standard easement agreement plus an easement for disposal systems to serve adjacent homes), and a mound system easement (for properties requiring a sand mound system, this easement allowed for the utility company to bring electrical service to the pump). The Peña Blanca WSD took over operation of the wastewater treatment system when construction was complete, and currently collects monthly user fees, contracts for septic tank pumping services, and schedules the biannual pumping of every septic tank. The City of Albuquerque accepts the septage. Users of the system pay (as of 1998) a "base" fee of $4.07 USD per month and an additional maintenance fee of $6.57 USD per month for a 1000-gallon septic tank.

The District has no formal measures in place to monitor performance or to review the management system. However, water samples from 16 private wells in 1998 found near background levels of nitrates in nearly every sample, and the District has successfully changed the rate structure once.

Additional Program Information

Capital Cost: $1,200,000 USD (septic leachfields, cluster systems, and sand mound disposal systems)
Management Model: On-Site Wastewater Management Program
Operation Cost: Monthly fee of $10.64 USD for a 1,000-gallon septic tank (covers biannual pumping provided by WSD)
Indicators of Success: Sampling of private wells in the area found nitrate nitrogen levels below 1 mg/L
Lessons Learned: Cost effectiveness was key to allowing this solution to be implemented

Contact Information

Theresa Armijo, General Manager
Pena Blanca Water & Sanitation District
(505) 465-2512

Related Links

http://www.nesc.wvu.edu/nodp/pdf/PenaBlanca.pdf
http://www.nesc.wvu.edu/nsfc/Articles/PL/PL_f01_Web/pl_f01_NewMexico.htm

Alternative Onsite Sewage Disposal Systems
U.S. Virgin Islands

Community Information

Status: U.S. Territory
Population: 121,000

Program Description

In many areas of the U.S. Virgin Islands (USVI), there is not two to four feet of pervious soil needed to construct a traditional on-site sewage disposal system. However, these areas may be distant from existing public sewer lines as to make connection to these lines prohibitively expensive. As the population and level of development of the USVI increased, it became necessary for the USVI to revise its sewage regulations and include alternative onsite sewage disposal systems. In the USVI, this alternative system usually consists of a constructed wetland. In this type of system, the septic tank overflows into a constructed wetland where the effluent undergoes secondary filtration. Plant evapotranspiration reduces the liquid load on the system, and any effluent remaining may be used in a "grey" water system.

The Department of Natural Resources (DNR) permits the alternative systems, whereas the Department of Health permits traditional systems. Permits for alternative systems are allowed only after a professional site evaluation has been performed demonstrating that the property is not suitable for a traditional system. This evaluation is reviewed by the DNR. All zoning code setback requirements must be met. The DNR recommends that owners of an alternative system pump the septic tank every three to four years, much like a traditional system. Sludge is not expected to build within the constructed wetland, as the septic tank contains three chambers to afford the most settling opportunities for any particles prior to effluent discharge to the constructed wetland. However, if sewage sludge builds up in the wetland cells, the soil and gravel media will have to be replaced and the wetland cells revegetated. The USVI feels that allowing the use of alternative systems is protective of human health and the environment and allows for the use of a property that would otherwise be unusable.

4.10 Useful Weblinks

U.S. EPA Septic System information
http://cfpub.epa.gov/owm/septic/home.cfm

U.S. EPA Municipal Technologies information
http://www.epa.gov/owm/mtb/index.htm

National Small Flows Clearinghouse
http://www.nesc.wvu.edu/nsfc/nsfc_index.htm

Hawaii Department of Health Wastewater Branch
http://www.hawaii.gov/health/environmental/water/wastewater/index.html

Hawaii Administrative Rules Title 11 Department of Health Chp. 62 Wastewater Systems
http://www.hawaii.gov/health/about/rules/11-62.pdf

Hawaii Guidelines for the Treatment and Use of Recycled Water
http://www.hawaii.gov/health/environmental/water/wastewater/pdf/reuse-final.pdf

National Sanitation Foundation certified Residential Wastewater Treatment Systems
http://www.nsf.org/certified/wastewater/Listings.asp?

The National Decentralized Water Resources Capacity Development Project
http://www.ndwrcdp.org/

National Onsite Wastewater Recycling Association
http://www.nowra.org/

Summary of Innovative/Alternative Technologies Approved for Use in Massachusetts
http://www.mass.gov/dep/brp/wwm/files/it/techsum.htm

Barnstable County Massachusetts Alternative Septic System Information Center
http://www.barnstablecountyhealth.org/AlternativeWebpage/index.htm

4.11 Annotated References

1. A Homeowner's Guide to Septic Systems, U. S. Environmental Protection Agency, EPA-832-B-02-005, 2002.

The information provided in the booklet is intended to help homeowners understand the function and maintenance of their septic system.

2. Buzzards Bay Project, Final comprehensive conservation management plan, August 1991.

This plan contains recommendations for limiting nitrogen input into the Buzzards Bay estuarine system.

3. Cantor and Knox. 1986. Septic system effects on ground water quality.

This report focuses on the various contaminants within septic system effluent and what effects those contaminants have on ground water quality.

4. Design Manual – Onsite Wastewater Treatment and Disposal Systems, U. S. Environmental Protection Agency, EPA 625/1-80-012, 1980.

This design manual provides basic technical information on generic types of onsite wastewater treatment and disposal systems and should be used as a reference document in conjunction with the current manual (see item 10).

5. Environmental Planning for Small Communities – A Guide for Local Decision-Makers, U. S. Environmental Protection Agency, EPA/625/R-94/009, 1994.

This book outlines a process for developing a community environmental plan.

6. Hall, M.W. 1975. A conceptual model of nutrient transport in subsurface soil systems, in Water pollution control in low density areas, University Press of New England.

This reference discusses the movement of nitrogen in the subsurface.

7. Horsley & Witten, Inc., 1998. Coastal resource management and protection workbook.

This workbook presents a variety of challenges in managing and protecting coastal resources.

8. Large Capacity Cesspools, Memo from Hawaii DOH, August 13, 2004.

This memo explains the conflicts between Chapter 11-62 and the U.S. EPA's UIC regulations, and what the state is doing to resolve the conflict.

9. Nielson, B. 1981. The consequences of nutrient enrichment in estuaries, Eutrophication Program Report, U.S. EPA Chesapeake Bay Program, Grant No. R-806-189-010.

This report discusses the negative results of excessive nitrogen inputs into an estuarine system.

10. Onsite Wastewater Treatment Systems Manual, U. S. Environmental Protection Agency, EPA/625/R-00/008, 2002.

This manual was developed to provide supplemental and new information for wastewater treatment professionals in both the public and private sectors and covers recent developments in treatment technologies, system design, and long-term system management.

11. Voluntary National Guidelines for Management of Onsite and Clustered (Decentralized) Wastewater Treatment Systems, U. S. Environmental Protection Agency, EPA 832-B-03-001, 2003.

The purpose of the Management Guidelines is to improve the level of performance of decentralized wastewater treatment systems nationally by raising the quality of management programs, establishing minimum levels of activity, and institutionalizing the concept of management.

12. Wastewater Treatment Programs Serving Small Communities, U. S. Environmental Protection Agency, EPA 832-R-02-004, 2002.

This brochure provides a brief overview of EPA and EPA-sponsored programs that provide assistance on wastewater issues to small communities.

13. Wetzel, R.G. 1983. Limnology, Saunders Co., USA, pp. 767.

This textbook mentions the role of nitrogen in algal blooms within coastal waters.

14. Weyer, P. J. Cerhan, B. Kross, G. Hallberg, J. Kantamneni, G. Breuer, M. Jones, W. Zheng, C. Lynch. 2001. Municipal drinking water nitrate level and cancer risk in older women: the Iowa women's health study, in Epidemiology, 12(3):327-338, May 2001.

This article discusses the risks of nitrates in drinking water as they relate to bladder cancer.

15. Yates, M.V. 1987. Septic tank siting to minimize the contamination of groundwater by microorganisms, U.S. Environmental Protection Agency pub. # 440/6-87-007, 87p.

This reference contains detail on how long viruses can survive in groundwater.

5 LID Resources

Better Site Design, Roadways, and Stormwater Resources

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