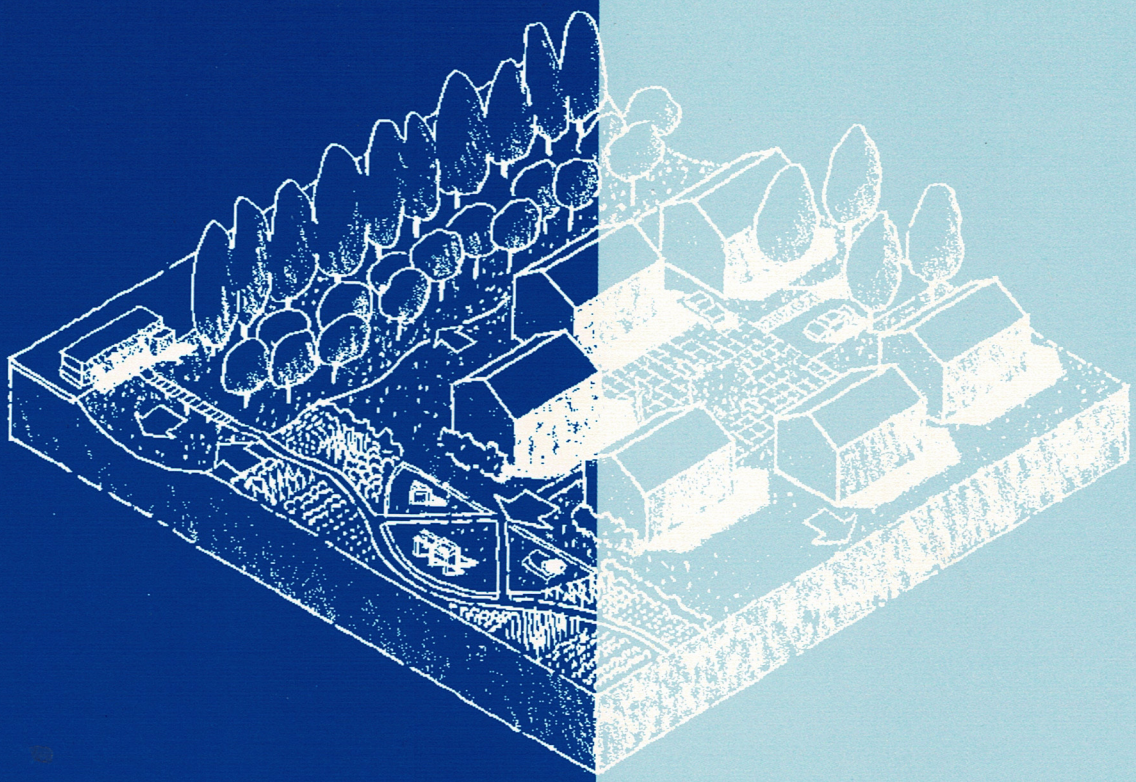
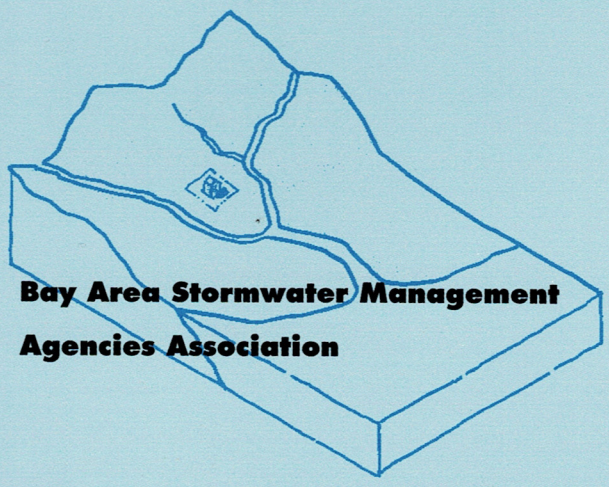


Start at the Source

Residential Site Planning

& Design Guidance Manual

for Stormwater Quality Protection



Bay Area Stormwater Management Agencies Association

BASMAA
Bay Area Stormwater Management Agencies Association

Tom Richman & Associates

Start at the Source

Residential Site Planning

& Design Guidance Manual

for Stormwater Quality Protection

January 1997

Bay Area Stormwater Management Agencies Association

B A S M A A
Bay Area
Stormwater Management
Agencies Association

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BASMAA Participating Programs

Alameda Countywide Clean Water Program
Contra Costa Clean Water Program
Fairfield-Suisun Urban Runoff Management Program
Marin County Stormwater Pollution Prevention Program
San Mateo Countywide Stormwater Pollution Prevention Program
Santa Clara Valley Urban Runoff Pollution Prevention Program
Vallejo Sanitation and Flood Control District

Geoff Brosseau, Executive Director, BASMAA
Tom Dalziel, Chairman, New Development Committee

It was developed under the guidance of a Review Committee comprised of representatives from regulatory agencies, planning departments, public works departments, builders, engineers, landscape architects, community activists, and members of the academic community. The development process spanned ten months, from January to October 1996. We are grateful for all the comments and suggestions provided by the Review Committee in development of this document.

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Foreword

The more we study stormwater runoff, the more we realize the critical role site planning and design play in our ability to reduce the impacts of development on the quality of our nation's waters. Unfortunately, most of the currently accepted site planning and design principles reduce water quality by increasing the volume of runoff and the amount of pollutants that reach surface waters. Once ignored, it is very difficult and expensive to reverse these impacts. This manual is a significant first step in teaching municipal planners and private developers to plan for water quality.

The San Francisco Bay Region of the California Regional Water Quality Control Board will use this manual to: 1) gauge the efforts of municipal storm water programs to implement their NPDES storm water permits and 2) review the efforts of developers to reduce the impacts of proposed development to a less than significant level as part of the CEQA process.

Thomas E. Mumley
California Regional Water Quality Control Board
San Francisco Bay Region
Urban Runoff Program Manager

Contents

"The more we study storm water runoff, the more we realize the critical role site planning and design play in our ability to reduce the impacts of development on the quality of our nation's waters."

Introduction by the Consulting Engineers end Land Surveyors of California (CELSOC)

BASMAA's "Start at the Source" guidance manual is a pioneering effort which focuses on the importance of considering storm water quality in the early stages of planning new residential development in the San Francisco Bay area.

The manual adds the planning of permanent "best management practices" to a list of on going efforts which have storm water quality as their goal. These efforts include heightening public awareness, care in construction practices, and the dedication of public agencies to increased maintenance efforts.

The planning of new residential projects is not only an activity conducted by planning and engineering professionals, it is equally an effort on the part of cities and counties to make difficult decisions about balancing what is important to their community within a reasonable range of affordability.

Water quality now joins an extensive and ever growing matrix of demands on new housing, some of which are conflicting. Many of these conflicting issues are pertinent to the subject at hand, and are touched on in this guidance manual. Providing compact development conflicts with the idea of minimizing impervious area, engineering solutions to high groundwater and expansive soils conflict with the desire to trap and percolate storm drainage; neo-traditionalism often conflicts with perceived desires of the homebuyer; the ideal of alternative means of transportation conflicts with Americans' love of their automotive freedom; and the ever growing demand on limited public funds makes dedicated maintenance of complex new pollution control systems difficult.

Most of all, the need for reasonably priced housing conflicts with the local, regional, and other agencies' unfortunate vision of new housing as a source of revenue to help solve social and environmental problems created by past practices. These "legacies" include diminishing wetlands, endangered species, school funding shortfalls, deteriorating transportation systems, lack of low cost housing, and even demands for child care.

It is with these challenges that federal, state, and especially local agencies considering these guidelines are encouraged to proceed in partnership with all sectors of private business and with the professional planning and engineering community to provide responsible, cost effective means of improving water quality.

Paul Meyer, Executive Director
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Consulting Engineers and Land Surveyors of California (CELSOC)

Consulting Engineers and Land Surveyors of California (CELSOC) is a statewide association of 850 professional engineering and land surveying firms in private practice which are dedicated to enhancing the consulting engineering and land surveying professions and protecting the general public.

Introduction by the American Society of Landscape Architects

Landscape architects are involved with design issues at every scale, from the setting of a catch basin to the layout of new towns. They deal principally with making places between buildings and the systems that link buildings and people together on the land. At the core of this place-making is grading and drainage– the shaping of the land to manage stormwater and accommodate human use.

Historically, grading and drainage design has largely neglected the environmental implications of stormwater runoff. In the past few years, we have begun to recognize the effect of stormwater runoff on environmental quality, especially on watershed and stream health. Today's designers must consider not only flood control and protection of property, but also how to minimize the creation of new runoff, and how to minimize the pollutants carried in that runoff.

The link between development and the quality of our environment is becoming increasingly evident. Though considerable professional attention has been given to direct stream and wetland protection, strategies for minimizing impacts of new development on watersheds have been less well articulated. This manual is an important step in showing how watershed protection can be achieved in urban and suburban development.

Through its integrative approach and illustrative method, "Start at the Source" shows how new development can be designed and built to meet functional and market demands while protecting water resources. It balances broad concepts with practical details. It provides a rationale for the design of places and the selection of building materials. It bridges the traditional gap between landscape architecture and civil engineering.

Finally, and perhaps most importantly, it shows how drainage systems can be integrated into overall site planning and landscape architecture to form the basis of practical, cost-effective, environmentally responsible, and aesthetically pleasing design.

Jim Dalton, Executive Vice President
American Society of Landscape Architects

The American Society of Landscape Architects is a professional association of over 11,000 members whose mission is "the advancement of the art and science of landscape architecture by leading and informing the public, by serving members, and by leading the profession in achieving quality in the natural and built environment."

http://www.asla.org/asla/

How to use this book

This document is intended for use in the **planning and design** phases of residential development and redevelopment. It recognizes that the one of the best opportunities to reduce the generation of "nonpoint source pollution" (see glossary) from development is through planning and design. Once developments are built, it is very difficult and expensive to correct land use patterns and stormwater systems that contribute to nonpoint source pollution.

Because the principles and techniques described here inform basic siting and design considerations, they will be easiest to incorporate and most effective if explored early in the planning and design of a project. Because of the wide variety of residential development sites in the Bay Area — such as infill, hillside, and redevelopment — and the wide array of regulations facing the development community — many of which are potentially in conflict with each other— the document suggests design and planning strategies for adaptation to each particular condition rather than mandating specific solutions for every case.

During the **construction period** additional strategies must be employed to minimize erosion and the introduction of other pollutants into stormwater runoff. These strategies, such as strawbale flow dissapators, silt fencing, and temporary erosion control matting, are documented elsewhere. For information on stormwater management during the construction phase, see the *California Storm Water Best Management Practice Handbooks (Construction Activity)* and the *Manual of Standards for Erosion & Sediment Control Measures* by the Association of Bay Area Governments (ABAG).

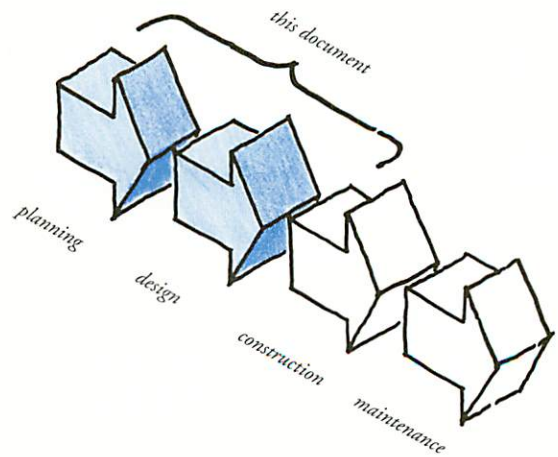
After construction, other practices must be employed for proper management of properties and facilities to prevent introduction of pollutants into the stormwater system. These "best management practices," such as proper storage and disposition of chemicals, recycling of oils, and community education, are also treated elsewhere. For a principal source of information on best management practices after construction see the *California Storm Water Best Management Practice Handbooks.*

This is not a technical handbook, but an illustrative design guidance manual. To keep the document from becoming burdensome, detailed explanation of how to calculate, construct, or design the various illustrated elements are not given here. Instead, the focus of this document is to communicate an approach and philosophy towards stormwater management. For those seeking more complete details on various techniques, a bibliography, resource list, and footnotes are provided for further reference.

This guidance manual is also not intended as a prescriptive document mandating that all projects adopt all the ideas presented here. Rather it is a menu of choices to illustrate a design philosophy and approach. Once the basic approach is understood, it is envisioned that each project team will adopt or adapt those solutions that best suit their unique circumstance.

The approach presented here implies some different ways of handling stormwater. Answers to **frequently asked questions** can be found on page 71.

This manual is not intended as a prescriptive document mandating that all projects adopt all the ideas presented here. Rather it is a menu of choices to illustrate a design philosophy and approach.



1 Introduction

This Manual has been prepared for the Bay Area Stormwater Management Agencies Association (BASMAA), an association of regional stormwater quality agencies around the San Francisco Bay and Delta.

Finding that the way we design and build communities has a direct effect on water quality, BASMAA has prepared this Manual with a focus on residential development, including new development, infill development and redevelopment. It aims to help designers, developers, and municipal agencies create residential communities that achieve water quality goals.

The Manual attempts to communicate basic stormwater management concepts and to illustrate simple, practical techniques to preserve the natural hydrologic cycle. These techniques are combined in a series of case studies to show how they may be integrated into residential projects. These case studies reflect the wide range of geographical, hydrological and market conditions found in the San Francisco Bay area.

For planners, designers and engineers accustomed to approaching stormwater management as a challenge in controlling large concentrated flows, the approach presented here may require a shift in thinking. Rather than considering only the large, infrequent storms normally associated with drainage and flood control, this document focuses on the small, frequent storms that have the most impact on urban water bodies, and shows how controls for smaller storms can be integrated into a comprehensive drainage system. Also, rather than considering the generally more expensive and complicated end-of-pipe solutions, this document seeks to illustrate the simpler, more economical stormwater management opportunities presented by starting at the source.

The way we design and build communities has a direct effect on water quality.

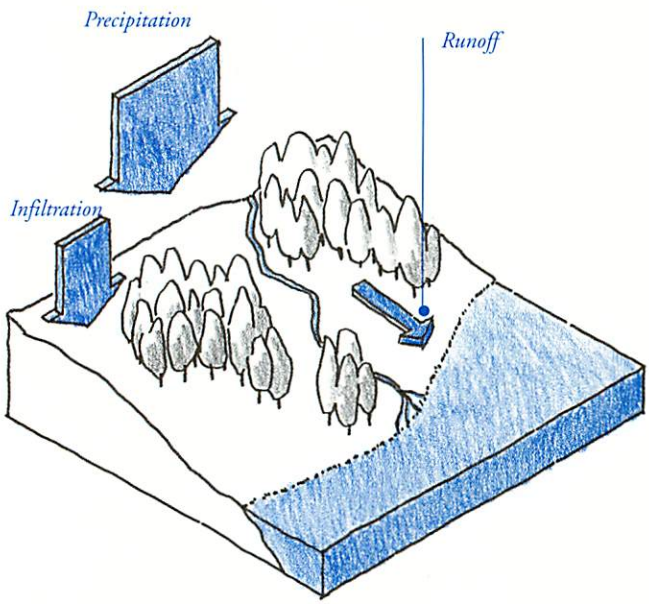
The Hydrologic Cycle

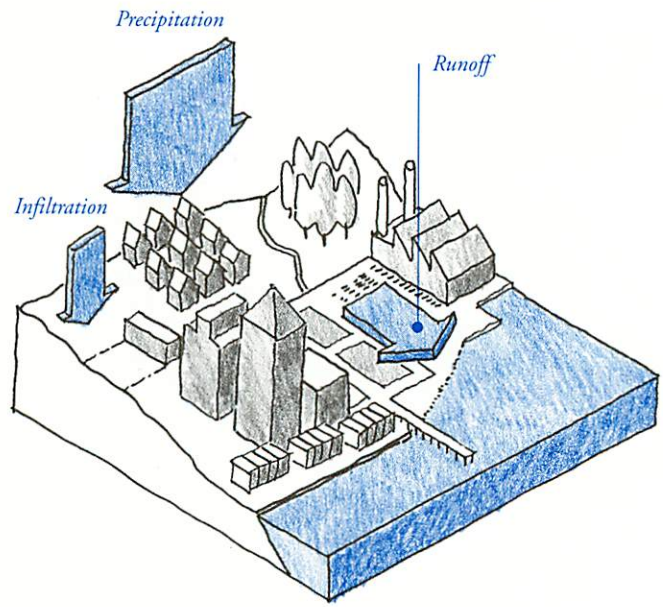
The continuous circulation of the earth's water from sky to land to sea to sky is called the Hydrologic Cycle.[1]

In its natural condition, soil is covered with a complex matrix of mulch, roots and pores which absorb rainwater. As rainwater infiltrates slowly into the soil, impurities are cleansed by natural biologic processes. Because most rain storms are not large enough to fully saturate the soil, only a small percentage of rainwater flows over the surface as runoff. What does become runoff usually travels in a slow meandering pace which allows suspended particles and sediments to settle. In the natural condition, the hydrologic cycle creates a stable supply of groundwater, and surface waters are naturally cleansed before arrival into the sea.

The impervious surfaces associated with urbanization prevent water from infiltrating into the soil. Even the smallest rainstorms generate runoff, which collects pollutants and sediments, and is concentrated in narrow channels or pipes. This rapid, concentrated water flow affects the hydrologic cycle in four ways: increased flood potential, channel destabilization, increased concentration of pollutants, and reduced groundwater levels.

Builders can can avoid these negative impacts by designing residential developments with stormwater systems that preserve and restore the natural hydrologic cycle.





The hydrologic cycle.

In **pre-development** landforms, a large percentage of precipitation infiltrates into the soil. A small percentage remains on the surface as runoff.

Post-development, opportunities for infiltration are typically reduced, and a larger proportion of total precipitation becomes surface runoff.

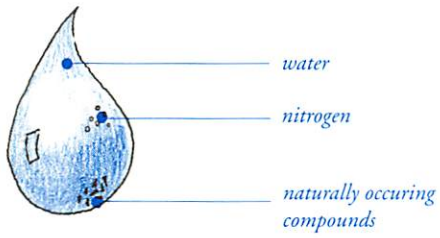
Regulatory Context

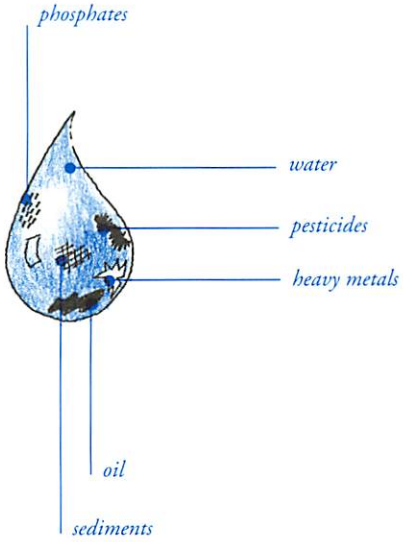
As rain falls, it picks up pollutants from the air. Then as it becomes runoff it collects more impurities while passing over rooftops, streets, parking lots, landscaping, and gutters. This runoff typically enters a storm drain system that rapidly conveys it to a lake, creek, river, bay or ocean. With the progress made in the past twenty-five years in controlling pollution from factories and other industrial point sources, this concentration of pollutants from various dispersed sources – "nonpoint source" pollution – is today responsible for up to 80% of the pollution in waters of the United States.[2]

The Clean Water Act of 1972, as amended in 1987, mandates that the discharge of stormwater into waters of the United States is effectively prohibited unless the discharge is in compliance with a National Pollutant Discharge Elimination System (NPDES) permit. In general, municipalities with population over 100,000 (or areas with contiguous municipalities whose aggregate population exceeds 100,000), industries, and construction projects that disturb five acres or more must obtain an NPDES permit in order to discharge stormwater runoff. Thus most Bay Area cities, and most large development projects, must comply with NPDES permit requirements.

The Municipal NPDES permit program requires that subject municipalities "develop, implement and enforce controls to reduce the discharge of pollutants from municipal separate storm sewers which receive discharges from areas of new development and significant redevelopment... [including] after construction is completed."[3]

Within this regulatory context, developers, and municipal permitting agencies are required to implement techniques that reduce water pollution carried in runoff. Reducing pollution in stormwater by capturing it at the source of runoff is a technically sound and cost effective strategy to bring residential development into compliance with Federal law.





What's in a drop of runoff?

Pre-development runoff generally contains water and a low concentration of naturally occuring compounds.

Post-development runoff contains water and a variety of pollutants collected and concentrated from impervious surfaces.

Impervious land coverage as an environmental indicator

A new environmental indicator is emerging to measure the health of urban watersheds — impervious land coverage.[4]

Impervious land coverage is a fundamental characteristic of urban and suburban areas. The rooftops, roadways, parking areas, and other impermeable surfaces of urban development cover soils that, before development, allowed rainwater to infiltrate. By depriving the soil of its ability to infiltrate rainwater, a host of environmental consequences follow.

One of the environmental consequences of impervious land coverage is stream degradation. Impervious surfaces associated with urbanization cause stream degradation in four ways:

1. Rainwater is prevented from moving into the soil, where it can recharge groundwater, reducing base stream flows.

2. Because it cannot infiltrate into the soil, more rainwater runs off, and runs off more quickly, causing increased flooding, destabilized natural channels, and associated reduction of habitat and other stream values. Flooding and channel destabilization may require construction to channelize the stream, with further loss of natural stream uses.

3. As runoff moves over large impervious areas, it collects and concentrates nonpoint source pollutants – pollution from cars, roadways, rooftops, etc. – increasing pollution in streams and other water bodies.

4. Impervious surfaces retain and reflect heat, causing increases in ambient air and water temperatures. Increased water temperature negatively impacts aquatic life and oxygen content of nearby waterbodies.

Impervious surfaces can be defined as any material that prevents the infiltration of water into the soil. While roads and rooftops are the most prevalent and easily identified types of impervious surface, other types include sidewalks, patios, bedrock outcrops, and compacted soil. As development alters the natural landscape, the percentage of the land covered by impervious surfaces increases.

Roofs and roads have been around many years, but the ubiquitous and impervious pavement we take for granted today is a relatively recent phenomenon. A nationwide road census showed that in 1904, 93 percent of the roads in America were unpaved. With the ascendancy of the automobile in the mid-twentieth century, the interstate highway system, and the growth of suburbia, the percentage of impervious surfaces increased dramatically. A prime contributor to the increase of impervious land coverage is the residential street network – since World War II, typical residential street widths have increased by 50%.

An increasing body of scientific research, conducted in many geographic areas and using many techniques, supports the theory that impervious land coverage is a reliable indicator of stream degradation. Furthermore, impervious land coverage is a practical measure of the impact of development on watersheds because:

– it is quantifiable, meaning that it can be easily recognized and calculated.

– it is integrative, meaning that it can estimate or predict cumulative water resource impacts independent of specific factors, helping to simplify the intimidating complexity surrounding nonpoint source pollution.

– it is conceptual, meaning that it can be easily understood by water resource scientists, municipal planners, landscape architects, developers, policy makers and citizens.

Water resource protection at the local and regional level is becoming more complex. A wide variety of regulatory agencies, diverse sources of nonpoint source pollution, and a multitude of stakeholders makes it difficult to achieve a consistent, easily understandable strategy for watershed protection. Impervious land coverage is emerging as a scientifically sound, easily communicated, and practical way to measure the impacts of new development on water quality.

This document illustrates a variety of site planning principles and design techniques for residential development. They all aim to reduce impervious land coverage, slow runoff, and to maximize opportunities for infiltration of rainwater into the soil.

Impervious land coverage thresholds.

A certain amount of impervious land coverage is unavoidable in any human development. Rooftops, by definition, must prevent infiltration of rainwater. Circulation systems– roads, parking, driveways– are the other, and usually most extensive, component of impervious land coverage. For planners, designers and regulators, the essential question is at what threshold of impervious land coverage does stream degradation begin?

Many recent studies have evaluated stream and wetland health using many criteria such as pollutant loads, habitat quality, and aquatic species abundance and diversity. These studies consistently show that significant water quality impacts begin at impervious land coverage levels of as little as 10%. At impervious land coverage over 30%, impacts on streams and wetlands becomes more severe, and degradation is almost unavoidable without special measures.

These impacts on stream health include:

– Creation of "new runoff," because soil that would normally absorb rainfall is covered with impervious surfaces.

– Streams receive greater flows more frequently. For example, flow equal to a pre-development 2–year storm may occur every 2–3 months after development.

– The stream channel, which is usually bank full in a 2–year storm, must enlarge itself to contain increased flows, causing bank erosion and loss of habitat.

– Bank erosion produces sediment which settles where and when velocities slow, covering aquatic vegetation and fish spawning beds, furthering the loss of habitat.

These studies suggest that three broad categories can be established using simple numeric thresholds illustrating the general relationship between impervious land coverage and stream health:

Impervious land coverage	*Stream health*
< 10%	"protected"
> 10 and < 30%	"impacted"
> 30%	"degraded"

These impervious land coverage percentages must be measured across an entire site or development area. Sometimes lower overall impervious coverage can be achieved by clustering development at higher densities on one portion of a site, while maintaining open space elsewhere.

Given land values and population densities in the Bay Area, less than 30% overall impervious coverage may be difficult to attain in many developments. Even in higher density developments, the impact of impervious land coverage can be mitigated by a variety of site planning and drainage techniques, which are illustrated in the following pages.

These techniques have three basic goals:

– to minimize overall impervious land coverage,

– to ensure that remaining impervious areas are not-directly-connected to an impervious storm drain system as far as feasible, and

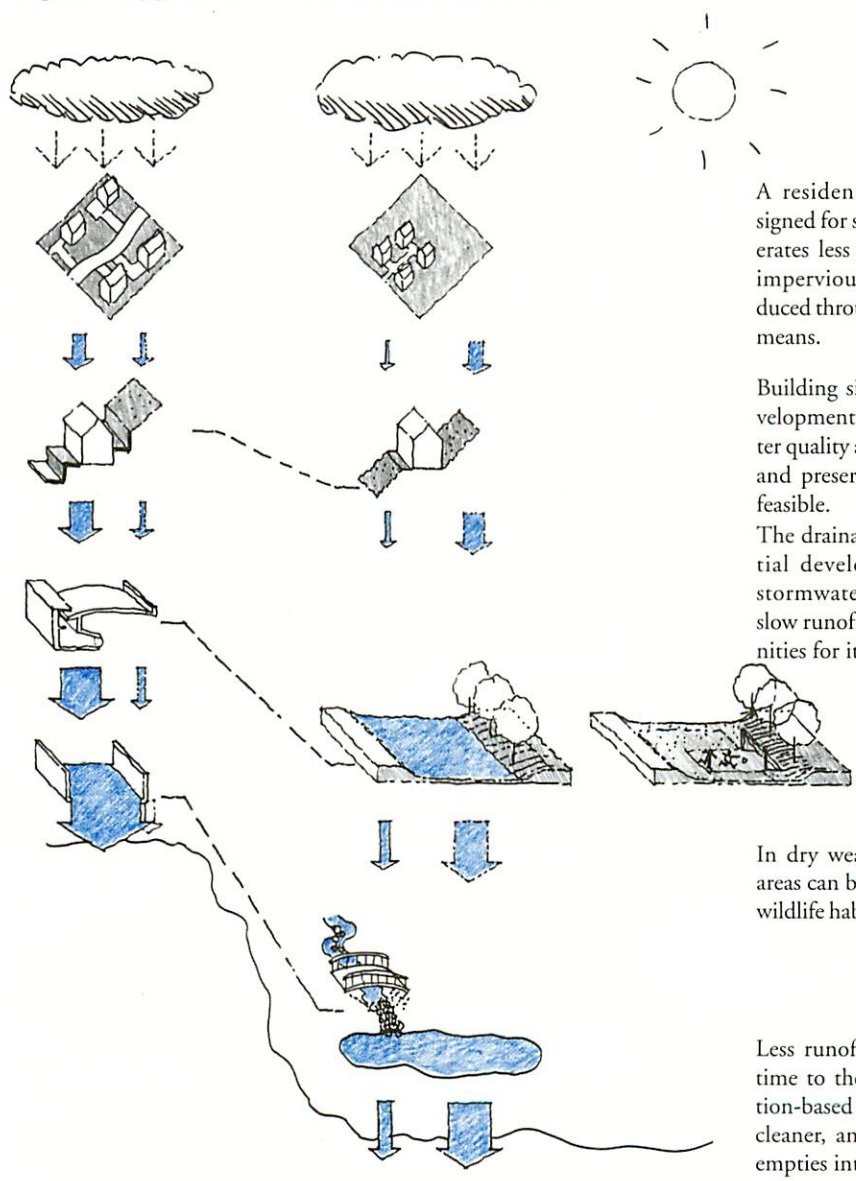
– to slow runoff within a drainage system.

Two approaches to stormwater management

The conveyance approach to stormwater management seeks to "get rid of the water." A conveyance stormwater system collects and concentrates runoff through a network of impervious gutters, drainage structures and underground pipes. As the conveyance system flows downstream, additional tributary conveyance systems feed into it, requiring it to be continually enlarged as it approaches its outfall. Because the system collects water from impermeable surfaces and carries it through impermeable pipes, suspended pollutants and sediments are concentrated in the rapidly flowing runoff. When the system reaches its outfall, large volumes of polluted water are emptied into a natural water body.

The infiltration approach to stormwater management seeks to "preserve and restore the hydrologic cycle." An infiltration stormwater system seeks to infiltrate runoff into the soil by allowing it to flow slowly over permeable surfaces. These permeable surfaces are designed to double as recreational and landscape areas during dry weather. Because the infiltration network allows much of the runoff to return to the soil, overall runoff volume is reduced, and more water is available to replenish groundwater and maintain stream base flows. The slow flow of runoff allows pollutants to settle into the soil where they are naturally cleansed. The reduced volume of runoff that remains takes a long time to reach the outfall, and when it empties into a natural water body, its pollutant load is greatly reduced.

Conveyance Approach **Infiltration Approach**



When rain falls on a conventional development, the extensive road network collects runoff.

A residential development designed for stormwater quality generates less runoff because overall impervious land coverage is reduced through clustering and other means.

Building sites in a conventional development may be graded severely, removing natural vegetation that absorbs runoff.

Building sites in a residential development designed for stormwater quality are fit into the contours, and preserve vegetation as far as feasible.

The drainage system in a residential development designed for stormwater quality attempts to slow runoff, and provide opportunities for it to filter into the soil.

The curbs, gutters and catchbasins in a conventional development collect runoff and carry it rapidly, providing little opportunity for infiltration.

In dry weather these infiltration areas can be used for recreation or wildlife habitat.

Large quantities of runoff are carried in a shorter time to the outfall of a conveyance stormwater system, carrying sediments and other pollutants as a fast flowing discharge into the bay.

Less runoff makes it in a longer time to the outfall of an infiltration-based stormwater system. It's cleaner, and moving slowly as it empties into the bay.

2 Concepts

A *few basic concepts form the foundation for drainage systems that preserve and restore the hydrologic cycle. Once these basic concepts are understood, the ingenuity of designers, planners and builders can be applied to invent specific techniques for the special requirements of any site.*

The concepts spring from an integrated, comprehensive approach to stormwater management, considering each site's unique position within a larger watershed, and each smaller watershed within a site.

The application of these concepts consistently within a site will create a stormwater management approach that minimizes impervious area, reduces direct connections between impervious areas, and mimics natural systems while being economical, aesthetically pleasing, and technically sound.

Concepts

2.1 Every site is in a watershed. Rain falls on every site. What happens to the rain depends on the site's place in the larger watershed, and on the smaller watersheds within the site. From where does water enter the site? To where does it go? Understanding that a site has a position in the larger context is essential to stormwater management.

2.2 Start at the source. What happens immediately after a drop of rain hits the ground? Rather than convey stormwater away for treatment at the end of a pipe, water quality is most easily and economically achieved if stormwater management starts at the point that water contacts the earth.

2.3 Think small. For decades planners, engineers and builders have been trained to think big– to design systems that will handle peak flows from the biggest storms. Yet most pollutants and flow-induced impacts to streams are in the early rains and small storms. Designing systems to accommodate the big storm is still essential for protection of life and property, but small-scale techniques, applied consistently over an entire watershed, can have a big impact — both improving stormwater quality and reducing peak flows.

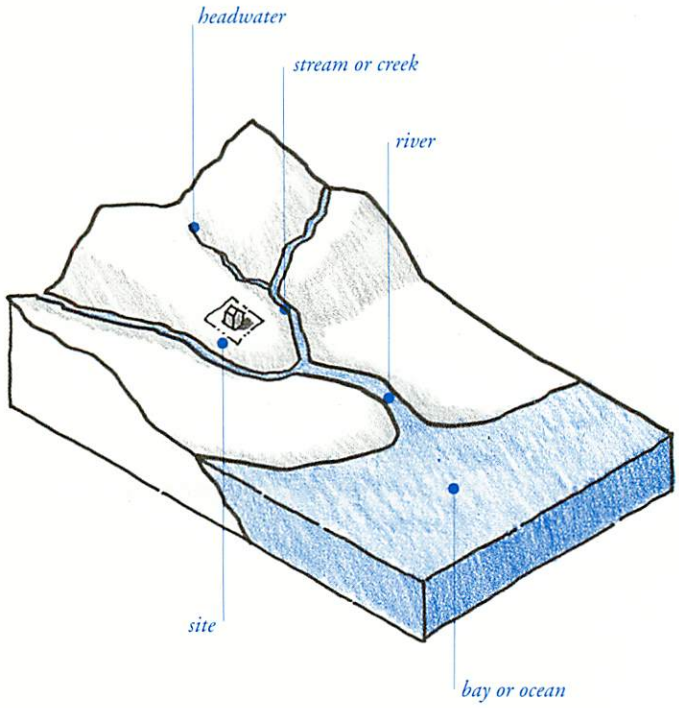
2.4 Keep it simple. A wide variety of simple and effective strategies can be employed to achieve stormwater quality goals. These simple strategies often use natural methods and materials, and sometimes require a different kind of engineering or maintenance than conventional modern drainage systems. Yet by employing an array of a few simple techniques throughout a site, improved stormwater management can be achieved economically with modest maintenance requirements.

2.5 Integrate the solutions. Providing stormwater management facilities is not a problem – it's an opportunity. By integrating solutions into the overall site plan, stormwater facilities can provide recreational, aesthetic, habitat, *and* water quality benefits.

Concepts

2.1 *Every site is in a watershed*

Once a single drop of rain reaches the earth, its journey is determined by the watershed in which it lands. A watershed is defined by the U.S. Environmental Protection Agency as "the geographic region within which water drains into a particular river, stream, or body of water."[5]



A small puddle in an uneven field reflects a tiny, localized watershed. At a neighborhood scale, gradual changes in elevation, or man-made artifacts like roadways or railroad embankments may define watersheds. Regionally, a range of mountain ridges may create a watershed that is drained by a network of small streams and creeks, each of which forms a tributary to larger water bodies, forming larger watersheds, all of which ultimately empty into a lake, bay or ocean.

No matter where you are in a watershed, or at what scale of watershed you are working, what you do on any particular site always has effects on the overall hyrologic system. By understanding that every site has a relationship to its adjoining watersheds, by investigating the soil and hydrologic conditions of the site, and by appreciating the micro-watersheds within each site, designers can best achieve the overall objective: restoration and preservation of the natural hydrologic system.

Concepts

2.2 *Start at the source*

W*hen a single drop of rain lands, it is carried by gravity and soil physics downward into the soil.*

If the soil is covered with an impervious material, such as rooftops, concrete, or asphalt, the single drop of rain flows along whatever surface it encounters, moving downhill, joining with other drops of rain to create runoff.

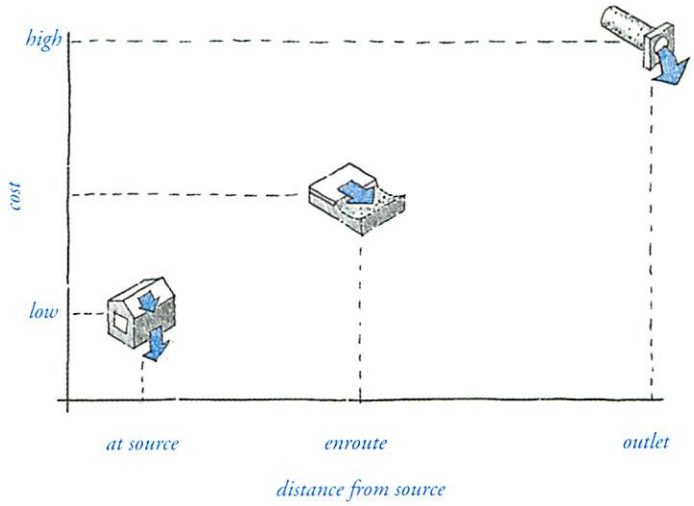
If this runoff is collected in pipes and conveyed long distances before treatment many opportunities for improved water quality are lost. "End of pipe" strategies, such as large retention ponds, can be important components of an overall stormwater management system, but are more complex and costly than strategies that start at the source.

Small collection strategies, located at the point where runoff initially meets the ground, repeated consistently over an entire project, will usually yield the greatest water quality improvements for the least cost.

Source control is cheapest

If runoff is infiltrated or detained at its source (a) no costs are incurred or special maintenance is required. If runoff is carried some distance and treated enroute (b), costs and maintenance demands rise. If runoff is carried directly to the outlet (c), cost for treatment controls are highest and most maintenance intensive.

The most economical, simplest stormwater management opportunities for water quality are at the source of the runoff.



Concepts

2.3 *Think small*

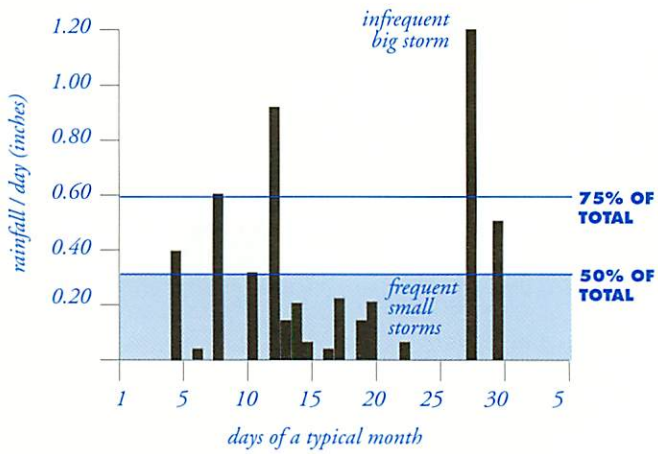
The most polluted urban runoff is usually generated by small storms, or by the first portion of a storm cycle. With the Bay Area's mediterranean-type climate, the oils, metals and other pollutants accumulated over the entire dry season are washed off rooftops, roadways and other surfaces in the first autumn rain. In subsequent storm cycles, this pattern is repeated, with the first rains carrying the highest concentration of pollutants. Thus, treating this "first flush" of runoff is the key to controlling nonpoint source pollution.

In the past, stormwater management has focused almost exclusively on flood protection. Systems that can accommodate these peak flows are more than adequate to convey small storms, which occur much more frequently. So, designers have been able to neglect the small storm and its impacts.

Yet, the small storms, because of their frequency and cumulative impacts, make the largest contribution to total annual runoff and have the greatest impact on water quality.

Small storms add up

Rainfall is distributed between relatively infrequent large storms and more frequent small storms. For example, at San Francisco International Airport the sum of all storms of 0.30 inches or less, plus the first 0.30 inches of all large storms, accounts for 50% of total annual rainfall.[6] A typical month's rainfall shows how the frequent small storms, plus the first increment of the big storms, accounts for half of the total rainfall volume.



Concepts

2.4 *Keep it simple*

The techniques illustrated in this document were purposefully kept simple. Being simple, they are easy to understand. They are also relatively easy and inexpensive to build and maintain.

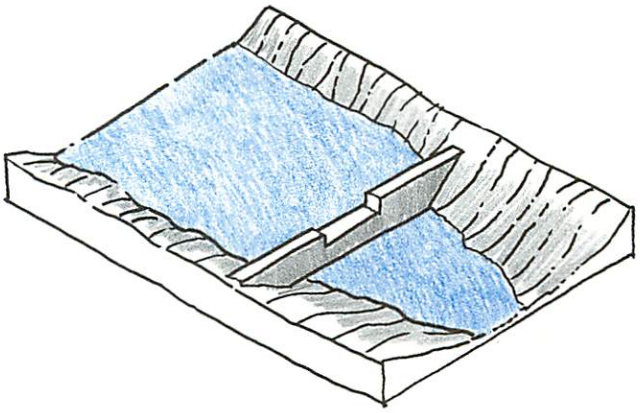
To address the many diverse sites found in the Bay Area, this document illustrates a wide variety of techniques, applicable to different soils, sites, and conditions. It is not intended that all *the techniques illustrated here will be appropriate for each project, but instead, that planners, landscape architects, and engineers select and adapt those few that are most well-suited to a particular site.*

A simple gravel strip, a concave instead of convex planting area, an infiltration basin at the end of a downspout — all of these are simple, but effective strategies for integrating stormwater management into a site plan.

The best stormwater management system will rely on a few simple techniques, applied consistently over an entire project or site.

Simple but effective

Because most stormwater management has generally been focused on complex, large systems, small, simple solutions may appear at first glance less effective. Yet simple solutions can be just as effective, and must undergo the same rigorous engineering analysis as more complex approaches. The difference is that the simple systems generally use lower technology materials and rely on natural materials integrated with the landscape, rather than mechanical or man-made processes, to manage stormwater.



Concepts

2.5 *Integrate the solutions*

The stormwater management system can become an organizing element for site planning and design. Infiltration devices, drainage swales, and retention areas can be integrated into a site plan to improve aesthetics and provide recreational resources.

For example, a grassy park, if slightly concave or depressed, can also serve as a temporary retention basin. Drainage swales can be landscaped with attractive riparian species. Pathways can follow these swales, creating attractive greenbelts that reflect natural landforms. A sandy area can serve as a children's playground in the dry season, but become a shallow infiltration basin in the winter rains.

Home buyers consistently indicate a preference for water features. A network of small ephemeral pools and swales, treated carefully with attractive planting and maintenance, can satisfy this desire for a relationship to water and give residential developments a competitive advantage.

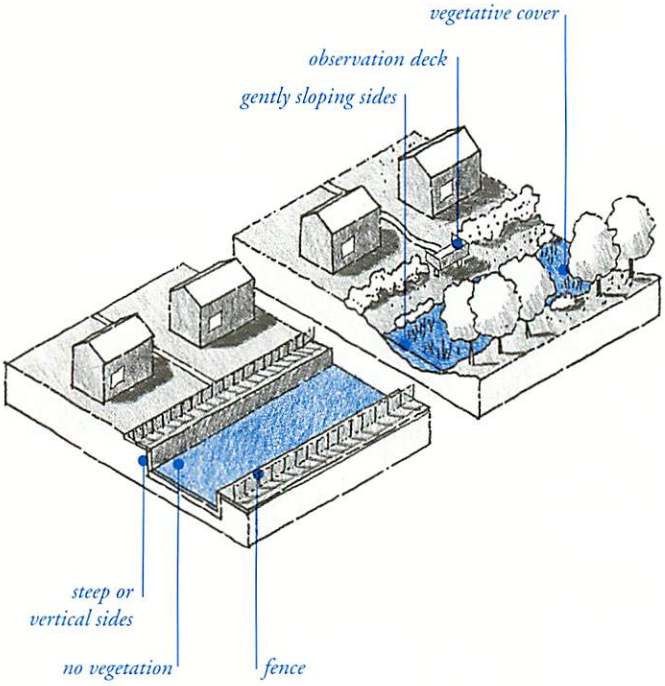
An integrated site plan will generally yield a series of smaller stormwater management facilities rather than one large basin at the end of a traditional conveyance system. This integrated approach not only reduces cost while achieving environmental goals, but it also maximizes land values, improves marketability, adds aesthetic interest, and provides increased recreational opportunities.

Design out the hazard, design in the people

Often environmentally sound stormwater management facilities, such as retention basins, are fenced or hidden from view. This approach to stormwater management not only adds significant "opportunity costs" through lost building sites or recreational potential, but also sends a symbolic message that stormwater is hazardous.

There are legitimate concerns for safety and liability, but they can usually be mitigated through simple design strategies such as shallow basin depths and gently sloping sides. By designing out the hazards and designing in the people, most drainage features can be integrated into the site plan to mimic the natural hydrologic cycle, add aesthetics, and increase recreational value.

Water as an amenity



Water as a hazard

3 Site Planning

The fundamental hydrological concepts and stormwater management concepts can be applied to site planning to generate residential forms that are more integrated with natural topography, that reinforce the hydrologic cycle, that are more aesthetically pleasing and that are often less expensive to build.

A few site planning principles help to locate development on the least sensitive portions of a site, and to create urban and suburban forms that accommodate residential land use while mitigating its impact on stormwater quality.

The application of these principles in developing a site plan will create opportunities for employment of a wide variety of simple design techniques to infiltrate significant amounts of runoff, improve aesthetics, and reduce development costs.

Site Planning

3.1 Define development envelope and protected areas. Each site possesses unique topographic and hydrological features, some of which are more suitable for development than others. By identifying the development envelope and protected areas, a site plan can be generated that minimizes both environmental impacts and construction costs.

3.2 Minimize directly connected impervious areas. For decades planners, engineers and builders have been trained to get rid of stormwater. This is accomplished by connecting impervious areas to storm drains. Yet these "directly connected impervious areas (DCIAs)" are a principal contributor to nonpoint source pollution and flow impacts.

3.3 Maximize permeability. A parallel strategy to minimizing DCIAs is to maximize the permeability of the site. This is accomplished both by preserving open space and by using permeable pavement surfaces where feasible.

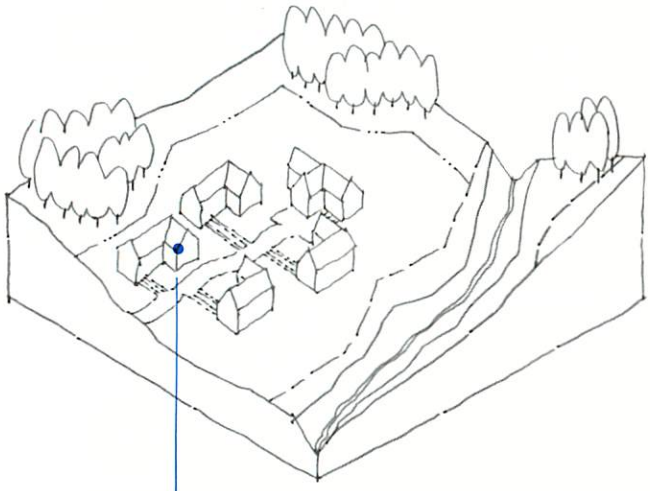
3.4 Employ "access" streets. More than any other single element, street design has a powerful impact on stormwater quality, both by generating large areas of impervious land coverage, and by collecting nonpoint source pollutants from automobiles. Alternative street standards and concepts allow for reduction of overall impervious land coverage and for more environmentally responsible treatment of roadway runoff.

3.5 Maximize choices for mobility. By planning for alternative modes of transport ation – bicycles, pedestrians, transit – reliance on automobiles can be reduced.

3.6 Use drainage as an organizing element. Unlike conveyance storm drain systems that hide water beneath the surface and work independently of surface topography, a drainage system for stormwater quality protection can work with natural land forms and land uses to become a major design element of a site plan.

Site Planning

3.1 *Define development envelope and protected areas*

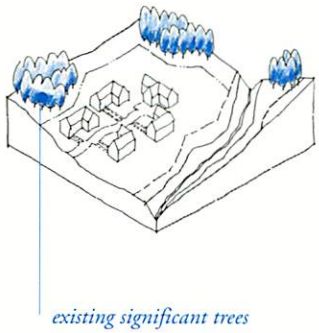


The first step in site planning is to define the development envelope. This is done by identifying protected areas, setbacks, easements and other site features, and by consulting applicable local standards and requirements. Site features to be protected may include important existing trees, steep slopes, erosive soils, riparian areas, or wetlands.

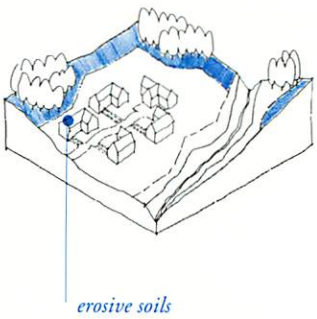
By keeping the development envelope compact, environmental impacts can be minimized, construction costs can be reduced, and many of the site's most attractive landscape features can be retained. In some cases economics or other factors may not allow avoidance of all sensitive areas. In these cases, care can be taken to mitigate the impacts of development through site work and other landscape treatments.

Set back development from creeks, wetlands, and riparian habitats.

Preserve significant trees. Trees protect soil structure, aid in soil permeability, and provide aesthetics.



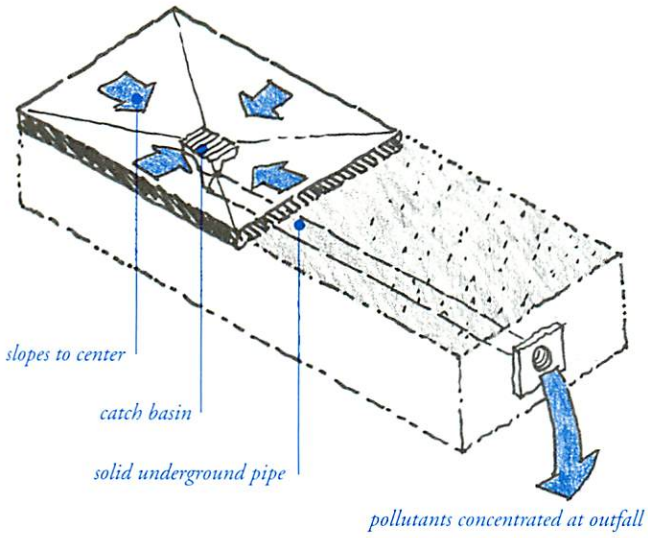
Avoid erosive soils and slopes. These include steep or long continuous slopes, soils high in silt or fine sand, or soils lacking vegetative cover.



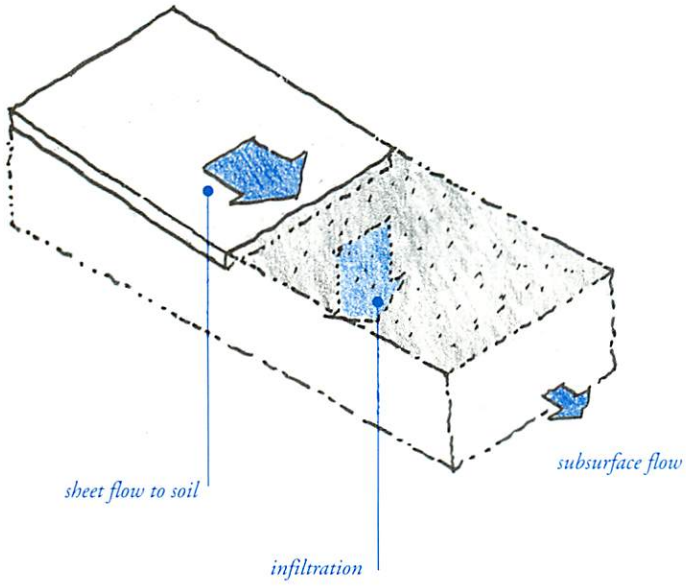
Site Planning

3.2 *Minimize "directly connected impervious areas"*

Directly connected impervious area (DCIA)



Not-directly connected impervious area

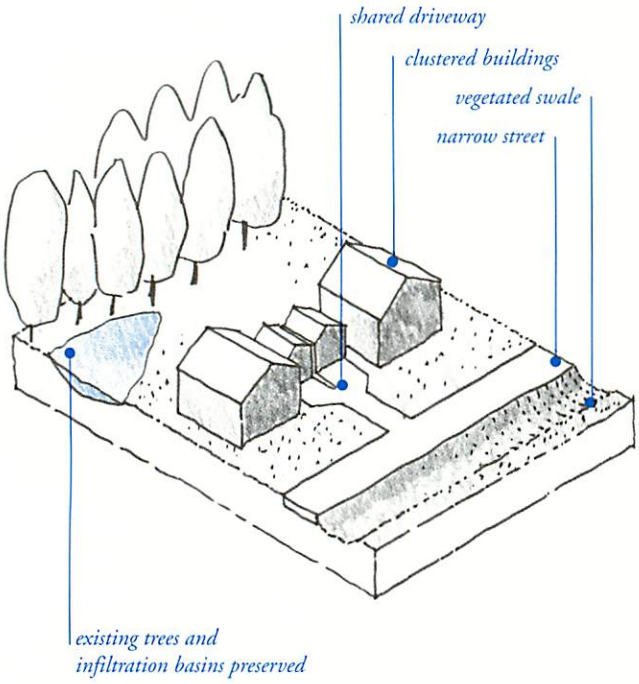


Impervious areas directly connected to the storm drain system are the greatest contributor to nonpoint source pollution. Any impervious surface which drains into a catch basin, area drain, or other conveyance structure is a "directly connected impervious area (DCIA)." As stormwater runoff flows across parking lots, roadways, and other paved areas, the oils, sediments, metals, and other pollutants are collected and concentrated. If this runoff is collected by a drainage structure and carried directly along impervious gutters or in sealed underground pipes, it has no opportunity for filtering by plant material or infiltration into the soil. It also increases in speed and volume, causing higher peak flows downstream, requiring larger capacity storm drain systems, increasing flood and erosion potential.

A basic site planning principle for stormwater management is to minimize these directly connected impervious areas. This can be done by limiting overall impervious land coverage or directing runoff from these impervious areas to pervious areas and/or small depressions, especially the first flush – the first 1/3 to 1/2 inch of rain. Larger storms may require an underground storm drain system, but even these systems can mitigate stormwater quality impacts if runoff from impervious surfaces passes through pervious areas and depressions before being collected in conveyance devices.

Site Planning

3.3 *Maximize permeability*



Within the development envelope, many opportunities are available to maximize the permeability of new construction. These include minimizing impervious areas, paving with permeable pavement materials, clustering buildings, and reducing the land coverage of buildings by building taller and narrower footprints. All of these strategies make more land available for infiltration and open space.

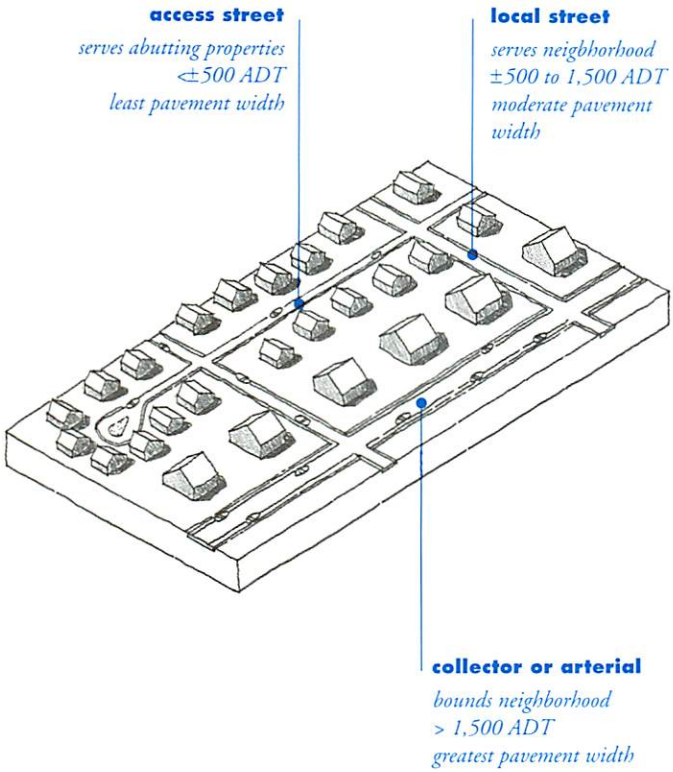
Clustered driveways, small visitor parking bays, and other strategies can also minimize the impact of transportation-related surfaces while still providing adequate access.

Once site coverage is minimized through clustering and careful planning, pavement surfaces can be selected for permeability. A patio of brick-on-sand, for example, is more permeable than a large concrete slab. Gravel, mulch, and lawns are permeable ground covers suitable for a wide variety of uses. Pervious concrete and porous asphalt, used in the eastern United States, are alternative materials that can preserve permeability where a larger, more intensely used paved area is needed.

Maximizing permeability at every possible opportunity requires the integration of many small strategies. These strategies will be reflected at all levels of a project, from site planning to materials selection. In addition to the environmental and aesthetic benefits, a high-permeability site plan may allow the reduction or elimination of expensive underground conveyance storm drain systems, yielding significant savings in development costs.

Site Planning

3.4 *Employ "access" streets*



More than any other single element, street design has a powerful impact on stormwater quality. In residential development, streets and other transport-related structures typically can comprise between 60 and 70% of the total impervious area, and, unlike rooftops, streets are almost always directly connected to an underground stormwater system.[7]

The combination of large, directly connected impervious areas, together with the pollutants generated by automobiles, makes the street network a principal contributor to nonpoint source pollution in residential areas. Locally, the Santa Clara Valley Urban Runoff Program estimated that automobiles were the source of half or more of the copper, cadmium and zinc in its waterways.[8]

Street design is usually mandated by local municipal standards. These standards have been developed since World War II to facilitate efficient automobile traffic and maximize parking. Most require large impervious land coverage, with a typical Bay Area local street standard mandating that 85% or more of the public right-of-way be covered with impervious pavement.

In recent years new street standards have been gaining acceptance that meet the access requirements of local residential streets while reducing impervious land coverage. These standards generally create a new class of street that is smaller than the current local street standard, called an "access" street. An access street is at the lowest end of the street hierarchy and is intended only to provide access to a limited number of residences.

Two approaches in particular have been implemented with success in various American communities: "neo-traditional design" and "headwaters streets."[9] Neo-traditional design seeks to emulate the tree-lined, compact streets found in pre-war, traditional residential neighborhoods. The headwaters streets concept suggests that streets be scaled to traffic volume just as stream size increases with water volume. Both strategies allot street space according to anticipated traffic levels rather than mandating a predetermined number of vehicle lanes.

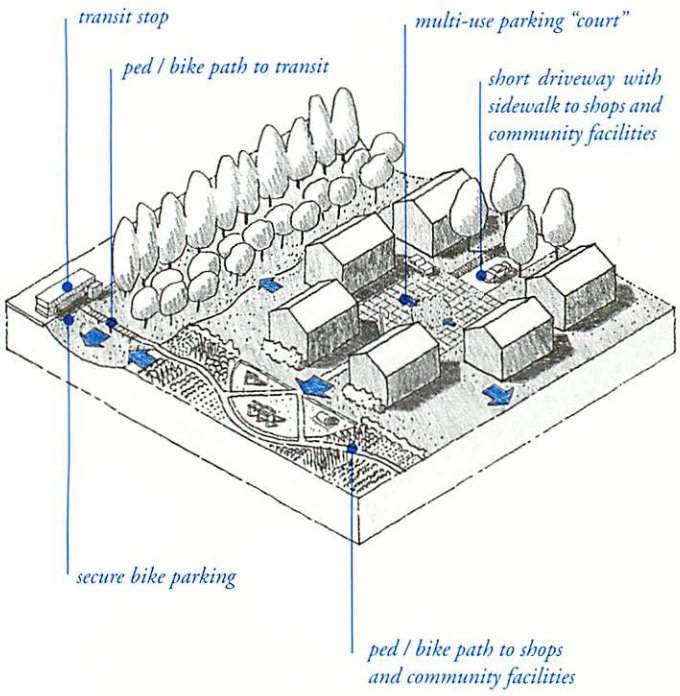
Recognizing that street design is the greatest factor in a residential development's impact on stormwater quality, it is important that designers, municipalities and developers employ street standards that reduce impervious land coverage.

For more information:
Details 5.2, Residential streets
page 37.

Site Planning

3.5

Maximize choices for mobility



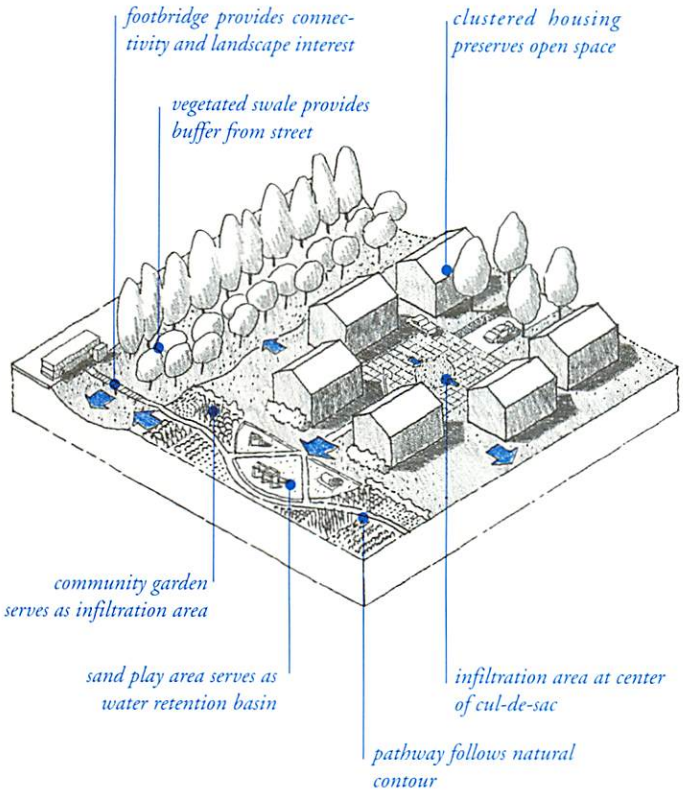
Given the costs of automobile use, both in land area consumed and pollutants generated, maximizing choices for mobility is a basic principle for environmentally responsible site planning. By designing residential developments to promote alternatives to automobile use, a primary source of stormwater pollution can be mitigated.

Bicycle lanes and paths, secure bicycle parking at community centers and shops, direct, safe pedestrian connections, and transit facilities are all site planning elements that maximize choices for mobility.

The automobile is a valuable, essential element of our current transportation system, and its use must be accommodated. But by giving comparable accommodation to other transportation modes, less environmentally costly choices for mobility become more viable.

Site Planning

3.6 *Use drainage as a design element*



Unlike conveyance storm drain systems that hide water beneath the surface and work independently of surface topography, a drainage system for stormwater infiltration can work with natural land forms and land uses to become a major design element of a site plan.

By applying stormwater management techniques early in the site plan development, the drainage system can suggest pathway alignment, optimum locations for parks and play areas, and potential building sites. In this way, the drainage system helps to generate urban form, giving the development an integral, more aesthetically pleasing relationship to the natural features of the site. Not only does the integrated site plan complement the land, it can also save on development costs by minimizing earthwork and expensive drainage structures.

Attractive? Yes. Nuisance? Not necessarily. Because of concerns about safety and liability, many developers and municipal agencies are reluctant to combine stormwater facilities with recreational uses. Yet, a well-designed stormwater facility can be safe and attractive.

This sand play area at Village Homes in Davis, California, doubles as a stormwater detention basin. Designed to hold about six inches of rainwater, this playground has been in use for over twenty years without any reported water-related accidents, lawsuits, or injuries.[10] It shows that multi-use stormwater management facilities can be both attractive and safe.

4 Drainage Systems

Conventional drainage systems are designed to achieve a single objective — flood control during large, infrequent storms. This objective is met by conveying and/or detaining peak runoff from large, infrequent storms. Drainage systems designed to meet a single flood control objective fail to address the dramatic increases in runoff volume and velocity caused by development. Increased runoff from small, frequent storms erodes urban streams and washes eroded sediment and other constituents from the urban landscape into downstream receiving waters, often damaging adjoining property and impairing their use by people and wildlife.

Today's drainage systems must cost-effectively manage flooding, control streambank erosion, and protect water quality. To do this, designers must integrate conventional flood control strategies for large, infrequent storms with three basic stormwater quality control strategies for small, frequent storms:

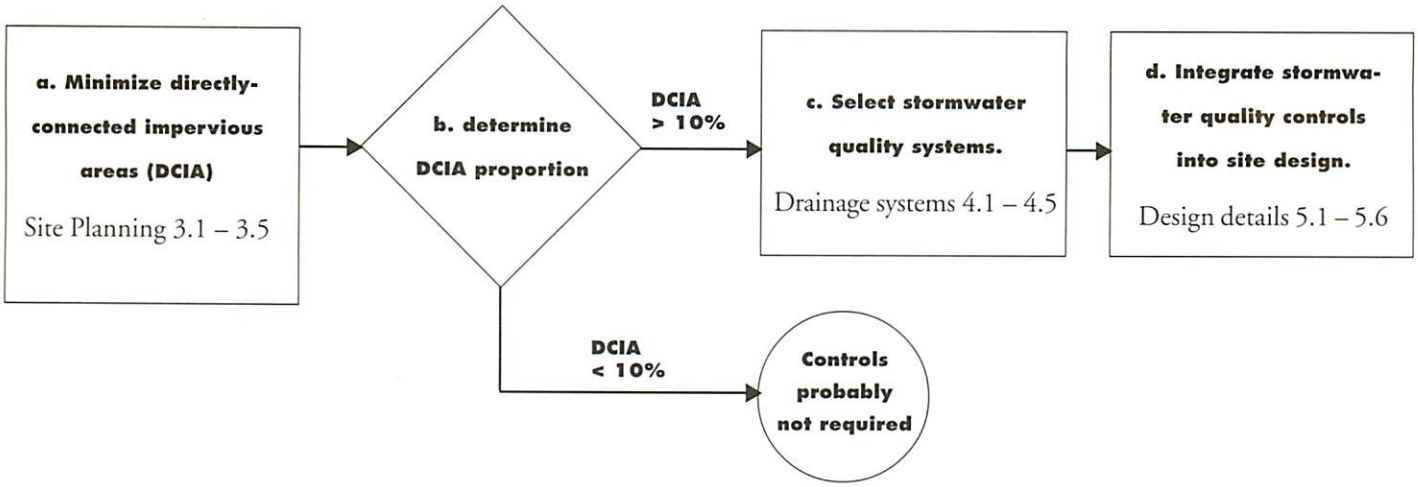
- *infiltrate runoff into the soil,*
- *retain/detain runoff for later release,*
- *convey runoff slowly through vegetation.*

Integrated flood control/stormwater quality control designs must meet a variety of engineering, horticultural, aesthetic, functional, economic, and safety standards. This chapter briefly outlines methods and criteria for drainage system design.

Drainage Systems

Today's drainage systems must cost-effectively manage flooding, control streambank erosion, and protect water quality.

Drainage system design process

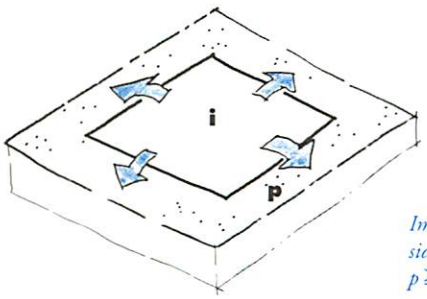


4.1 Drainage system design process

The simple design process described below establishes the foundation of a drainage system for stormwater quality.

a. Minimize directly connected impervious area (DCIA). Using the concepts and site planning principles outlined previously, design a project to minimize directly connected impervious area.

The DCIA is measured by adding together the square footage of all impervious surfaces that flow directly into a conveyance stormwater system. These impervious surfaces are principally comprised of rooftops and conventional pavements. Impervious surfaces that are not directly connected to a conveyance system are not included in the calculation of DCIA. However, to be considered "disconnected," intervening pervious areas receiving runoff (p) must be at least one half the size of impervious surface areas generating runoff (i). The impervious area must also be of appropriate width and slope to effectively slow runoff.[11]



Impervious areas are considered "disconnected" if: $p \geq 1/2\ i$

b. Determine site DCIA proportion. If the site DCIA coverage is less than 10 percent, urban streams are generally not impaired and stormwater management controls are probably not required. If DCIA coverage is between 10 and 30 percent, stormwater quality control may be needed to minimize stream impairment. If DCIA coverage exceeds 30 percent, some form of stormwater quality control is probably needed (see page 5).

c. Select stormwater quality systems. There are three stormwater quality control systems appropriate for residential development in the Bay Area: infiltration, detention/retention, and biofilters (see Drainage systems 4.4). Using these approaches, alone or in combination depending on site conditions (4.2) and soils (4.3), drainage systems can be designed to reduce flows and remove pollutants.

d. Integrate stormwater quality controls into site design. The Design Details section (Chapter 5) describes the many opportunities available to site designers for reducing DCIA and incorporating stormwater quality controls into residential site design. Local municipalities and developers can evaluate their particular opportunities and constraints to determine practical solutions within the framework presented here.

Site conditions

4.2 Site conditions.
Site designers and municipal site plan reviewers must understand site conditions and use these as the basis for selecting appropriate stormwater quality controls.

a. Local climate. The Bay Area is distinctive for its widely varied local climates. Local climate will influence selection of controls for a specific site. For example, controls that rely upon vegetation to stabilize soils and filter pollutants may be appropriate in coastal areas with more moisture and/or moderate temperatures, while pervious pavements may be better in hotter, drier portions of the Bay region where vegetation must be more heavily irrigated.

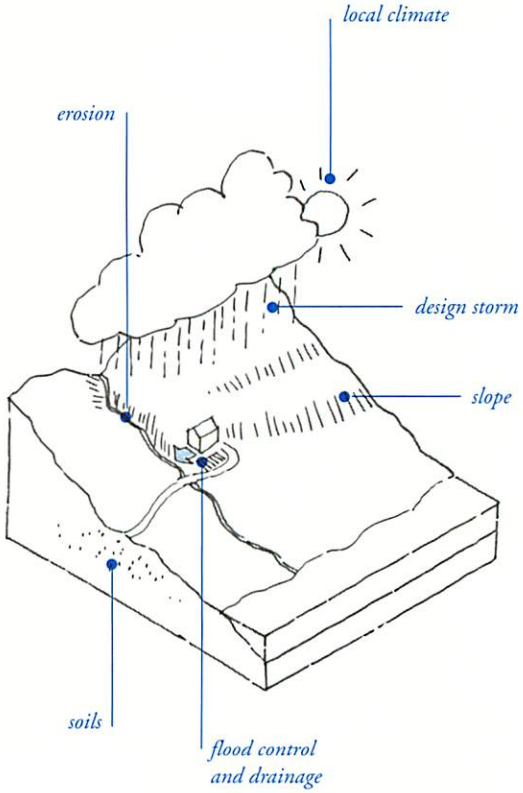
b. "Design storm" size. Design storms used to size stormwater quality controls are significantly different than those used for conventional drainage and flood control facilities. Stormwater quality design storms generally are based on the capture of a certain fraction of the average annual runoff from the site or development. The rainfall analysis presented in the California Storm Water Best Management Practices Handbook indicates the most "cost-effective" level of stormwater quality protection occurs when about 75 to 85 percent of the average annual rainfall is captured and held long enough to allow about 80 percent of the suspended solids to settle (between 12 and 40 hours). This design storm volume ranges between 1 and 1.6 times the average storm volume of about 0.05 feet (0.6 inches) in the Bay area.[12] The actual design storm volume within this range depends on the drawdown time of the selected stormwater quality control.

c. Soils. Site designers must know the soils at the site when considering infiltration measures including pervious pavements. Soil conditions will determine whether a site is suitable for infiltration, or if a detention/retention system is required. See 4.3 Soils.

d. Erosion. Erosive soils impair the effectiveness of most stormwater quality controls, and must be stabilized before installing these controls. Excessive sediment clogs infiltration devices, rapidly fills detention basins, and covers vegetative measures.

e. Slope. Most stormwater quality controls are sensitive to the slope of local terrain. Biofilters and infiltration basins cannot be used in steep terrain, while detention basins usually can be made to work on any reasonably sized land parcel.

f. Flood control and drainage. Stormwater quality controls are sized to capture runoff from storms much smaller than those used to size drainage and flood control systems. Site developers should first consider an integrated system that achieves both stormwater quality and flood control objectives. In these integrated systems, runoff from small storms and the "first flush" of larger storms enters the stormwater quality control system. Flows exceeding the runoff volume of the stormwater quality control system are either bypassed into a separate drainage/flood control system or accommodated within the stormwater quality control system (as long as these larger flows do not "flush out" the pollutants captured from smaller storms). In some cases, traditional drainage/flood control systems can be eliminated at a significant cost savings to the developer.



4.2 Site conditions

Soils

4.3 Soils

The USDA Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS) classifies a soil's hydrologic effects into four Hydrologic Soil Groups (HSG), labeled A through D. Group A and B soils possess the greatest infiltration rates (unless soils are compacted during construction) and are generally suited to stormwater infiltration. However, the Bay Area has a relatively high concentration of Group C and D soils, which possess lower infiltration rates that generally limit use of infiltration.

Some soils have compound classifications, such as A/D. This indicates that the natural soil is in group D because of a high water table which impedes infiltration and transmission, but following artificial drainage using such methods as perforated pipe underdrains, the soil's classification is changed to A, making it more appropriate for infiltration with proper site design.

For a specific site, the HSG designation can be obtained by referring to a local soil survey, by consulting the complete national listing given in the NRCS Technical Release 55, or by performing an on-site investigation. The accompanying table presents soil infiltration rates for each soil group determined by laboratory studies and measurements. Site designers should compare the design runoff volume with the available soil storage volume to determine if infiltration is feasible, and then use the infiltration rates to determine if the design runoff volume can infiltrate within a reasonable time (generally 24 to 48 hours).

For sites with Group C and D soils, retention- and detention-based strategies are often more feasible that infiltration designs.

Hydrologic soil groups (HSG)

Group A: Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well-drained sands or gravels. These soils have a high rate of water transmission.

Group B: Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained sandy loam soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C: Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of silty-loam soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D: High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Typical soil infiltration rates.

Soil Type	*Infiltration Rate (wet soil)*	*Soil Storage*	*Impervious area to infiltration area ratio**	
			24 hour drawdown	*48 hour drawdown*
A	1.00 in/hr	6.75 inches	7.7	6.3
B	0.50	5.00	5.4	4.4
C	0.25	3.80	3.9	3.1
D	0.10	1.40	0.8	0.5

These are typical rates which may be lower due to natural site conditions such as high groundwater, bedrock and impermeable clay layers. * For 80% capture of average annual storm volume in Bay Area.

Drainage system elements

4.4 Drainage system elements

Drainage systems for residential development can achieve stormwater management goals by using one of three basic elements, either alone or in combination, depending on site and other conditions: infiltration, retention/detention, and biofilters.

4.4a Infiltration. Infiltration is ideal for management and conservation of runoff because it filters pollutants through the soil and restores natural flows to groundwater and downstream water bodies. Infiltration systems are designed to infiltrate the majority of runoff from small storms into the soil rather than discharging it into a surface water body. Infiltration basins can range from a single shallow depression in a lawn, to an integrated swale, pond, and underground storage basin network.

Site soil conditions generally determine if infiltration is feasible. In Soil Groups A and B (see 4.3) infiltration is usually acceptable, but severely limited in Soil Groups C and D, or where high groundwater, steep slopes, or shallow bedrock is present.

Infiltration basins can be either open or closed. Open infiltration basins, which include ponds, swales, and other landscape features, are usually vegetated – the vegetation maintains the porous soil structure and reduces erosion. Closed infiltration basins can be constructed under the land surface with open graded crushed stone, leaving the surface to be used for parking or other uses. Subsurface, closed basins are generally more expensive than surface systems, and are used primarily where high land costs demand that the land surface be reclaimed for economic use.

Infiltration systems have been used by many local jurisdictions in California and CalTrans for about three decades[13], though heavy Bay Area soils sometimes limit their local application. The basic design goal of infiltration systems is to provide opportunities for rainwater to enter the soil. This is generally accomplished by retarding the flow of runoff, and by bringing it in contact with the soil, either by holding it in ponds or moving it slowly along the ground surface. Infiltration basins are most economical if placed near the source of runoff, but they should be avoided on steep, unstable slopes or near building foundations.

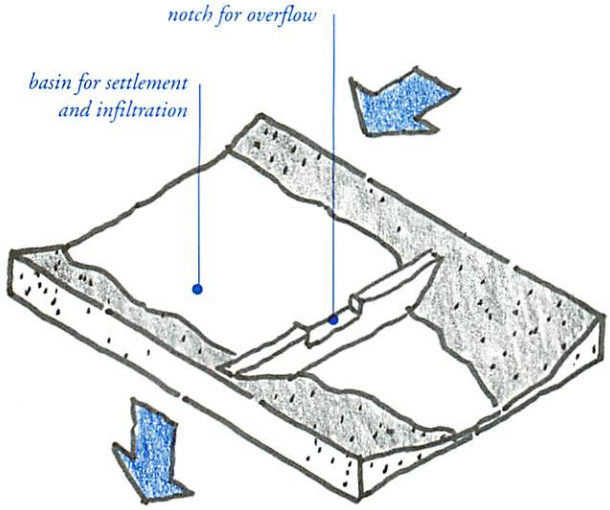
Concerns with infiltration systems are clogging, and contamination of groundwater from pollutants able to migrate through the soil (e.g. nitrates, solvents), and impacts on slope stability of hillside sites.

Clogging may occur in very fine soils, and infiltration systems are best suited to loamy and well-drained soils. Poorly drained, clay soils may not provide adequate percolation. Infiltration basins are best installed at the end of construction, as construction-related runoff may contain a high proportion of silts which can clog the basin floor.

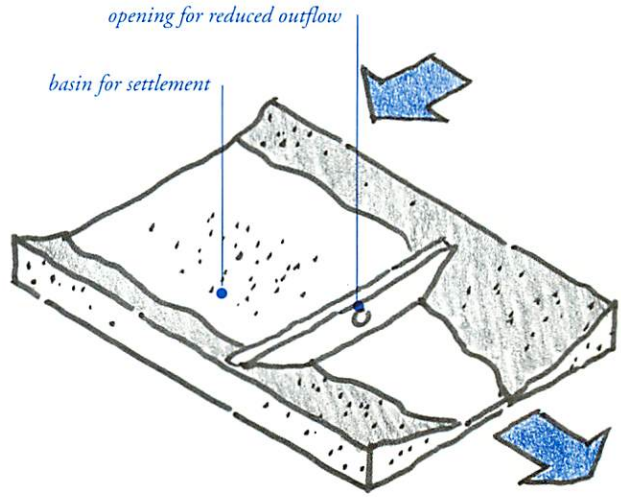
Residential developments present the least potential of contamination of groundwater or soil from infiltration systems, according to a recent study completed by the EPA.[14] This is because residential developments generally have low concentrations of pollutants with low solubility and mobility. High concentrations, when they occur, such as an oil spill in a driveway, are localized and small. Based on recent EPA analysis of groundwater protection and infiltration, the Santa Clara Valley Water District, for example, is currently revising their policy to permit infiltration basins 10 feet or less in depth.[15]

Risk of groundwater contamination from residential infiltration systems is further minimized by the findings that metals tend to remain within upper one foot of depth. Organics such as petroleum hydrocarbons migrate slowly downward– allowing natural degradation to occur. Furthermore, drinking water is typically drawn from significantly greater depths. In the Santa Clara Valley, for example, wells pumped for drinking water supply are deeper than 50 feet by ordinance. In some portions of the valley, water companies pump from much deeper aquifers, in the range of 400 feet. [16]

4.4b Retention and detention. Retention and detention systems differ from infiltration systems primarily in intent. While infiltration systems are intended to percolate water into the soil, retention/detention systems are designed primarily to store runoff for later release. Detention systems store runoff for one to two days after a storm and are dry until the next storm. Retention systems usually have a permanent pool that retains the runoff volume until it is replaced during the following storm. Properly designed retention/detention systems release runoff slowly



4.4a Infiltration basin



4.4b Retention/detention basin

enough to reduce downstream peak flows to their pre-development levels, allow fine sediments to settle, and uptake dissolved nutrients in the runoff where wetland vegetation is included. Retention/detention systems are most appropriate for areas with silt and expansive clay soils (HSG C and D), where limited infiltration occurs under pre-development conditions and reducing post-development runoff peaks is generally sufficient because the difference between pre-development and post-development runoff volume is often small.

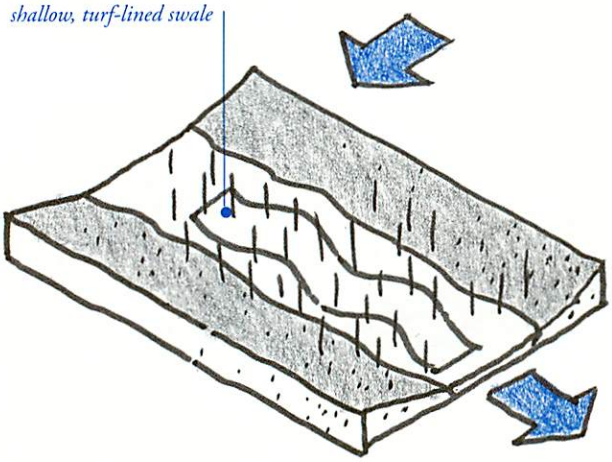
The permanent pool of a retention system and the storage volume in a detention basin are both sized equal to the runoff volume from the stormwater quality design storm, plus an additional 20 percent of this volume for sediment storage. Detention system outlets are generally sized to release 50 percent of this volume within 12 to 16 hours, and the remainder in another 24 to 32 hours.

Outlets of detention systems serving areas less than 10 acres are usually less than 3 inches in diameter and may clog easily if not properly designed and maintained. Retention system outlets must both maintain the permanent pool and slowly release runoff during each storm. Retention times in the permanent pool commonly are set at one to three days for removal of fine sediments, and up to two weeks for removal of dissolved nutrients through biological uptake by wetland vegetation. Common outlet designs are orifices, perforated risers, and V-notch weirs, with an emergency spillway provided to safely convey storms larger than the stormwater quality design storm.

4.4c Biofilters. Biofilters are vegetated slopes and channels designed and maintained to transport shallow depths of runoff slowly over vegetation. Biofilters are effective if flows are slow and depths are shallow. This is generally achieved by grading the site and sloping pavement in a way that promotes sheet flow of runoff. For biofilter systems, features that concentrate flow, such as curb and gutter, paved inverts, and long drainage pathways across pavement, must be minimized. The slow movement of runoff through the vegetation provides an opportunity for sediments and particulates to be filtered and degraded through biological activity. In most soils, the biofilter also provides an opportunity for stormwater infiltration, which further removes pollutants and reduces runoff volumes.

Slow, shallow sheet flow is maintained in the biofilter by constructing it with gently sloping sides (3:1 slope max.), minimal longitudinal slope (1 to 2% recommended, with check dams for steeper slopes), and a flowpath length of at least 10 feet. The key concept is to move water slowly through the vegetation. The most common ground cover material is turfgrass, which

Drainage system elements (continued)



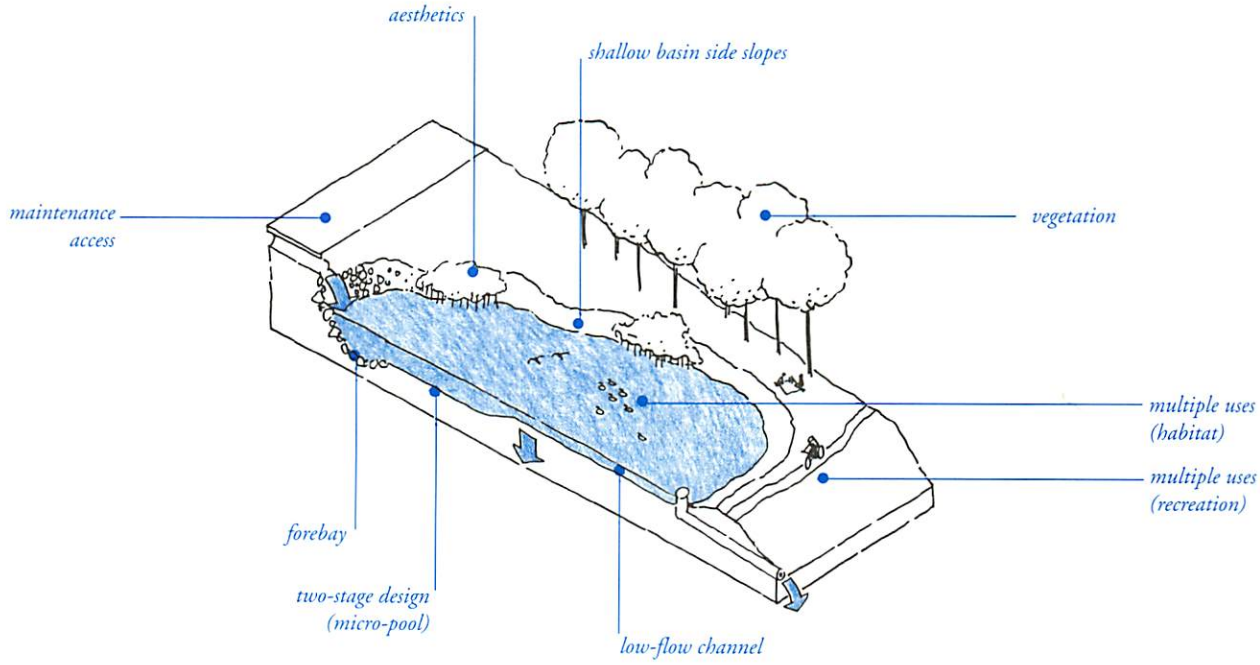
4.4c Biofilter

must be irrigated through the dry season. For a turfgrass lined biofilter to work effectively, the turf must be mowed regularly and the cuttings removed.[17] Where slopes are less than 1% or where groundwater is high, wetland vegetation can be used in biofilters. Clay soils, or soils where vegetation are inhibited, are generally not appropriate for biofilters.

Biofilters are especially applicable to parking lots, as the long aisles can be sloped into linear grass swales to collect and treat runoff from pavement surfaces. Adjacent pavement elevations should be set slightly higher than the adjacent biofilter. If water enters at concentrated points, as opposed to sheet flow, erosion control should be included at inlets and outlets.[18]

Biofilters should be designed using the stormwater quality design storm. The peak depth of the hydrograph should be less than 3 inches and peak velocity less than 1 ft/second. Large storms should bypass the biofilter, or the biofilter should be sized to accommodate larger storms while meeting water quality criteria. The bottom width of the swale is generally 2 to 8 feet, with grass height of 4 to 6 inches and maximum water depth of less than 2 inches.

System design techniques



4.5 System design techniques

A variety of techniques are available to design stormwater management systems for water quality protection so that safety and aesthetics are maximized while minimizing maintenance. A key element of system design is to provide a means for managing the runoff from large storms – either a spillway or an embankment designed to withstand overtopping. The stormwater management system is usually comprised of a series of individual elements – basins, swales and pipes – in an interconnected, continuous system. Some of the techniques available to integrate these elements into the site plan and improve their functionality include:

a. Two-stage design. Place 15 to 25% of the volume at a lower stage to create a micro-pool that fills often, keeping the rest of the basin dry and sediment-free most of the time.

b. Basin side slopes. Set side slopes at 4:1 or flatter to prevent bank erosion and minimize risk of drowning.

c. Forebay. Design basins so that larger particles settle in depressions at basin inlets, and so inflows do not erode or resuspend materials in forebay.

d. Low flow channel. A low-flow channel conveys dry-weather flows and the last of captured volume to the basin outlet.

e. Vegetation. Plant vegetation to control erosion and enhance sediment entrapment.

f. Maintenance access. Access for maintenance must be included in the design of all elements. While most smaller basins and swales can be serviced by typical garden maintenance methods, larger basins may require stable vehicular access ways to forebays and outlets for periodic cleaning or dredging.

g. Multiple uses. Incorporate flood control, recreational facilities, landscaping, and/or wildlife habitat into system design.

h. Aesthetics. Integrate the basins and swales into the site to take advantage of the aesthetic qualities of water and plant materials.

5 Design Details

Once a site plan is generated, a multitude of small design decisions must be made, each of which will affect the hydrology of a development. These design decisions include selection of paving materials, collection of roof runoff, grading of landscaped areas, and many other details.

Any particular detail may make little difference in the overall impact of a development, but taken together, these details exert a profound influence on the ability of a development to meet stormwater quality goals. Consistent with the concept of starting at the source, these details look for opportunities to manage small quantities of runoff at many diverse locations throughout a site. The watchword for maximizing stormwater control is "do what you can where you can."

A variety of design techniques and details are presented in this chapter. Each illustrates an approach to design and construction for maximizing infiltration, providing retention, slowing runoff, and minimizing impervious land coverage. The techniques presented here are not all-inclusive, and may not be appropriate for every site or condition, but it is hoped that, once the intent of these details is understood, designers and builders will use their ingenuity to develop additional strategies consistent with water quality goals.

Design Details

Do what you can where you can.

Design Details Matrix

This matrix summarizes the details described on the following pages by their initial construction cost, maintenance cost, relative effectiveness at meeting stormwater quality goals, and their suitability for use in expansive, clay soils. Conventional approaches are also evaluated for comparison.

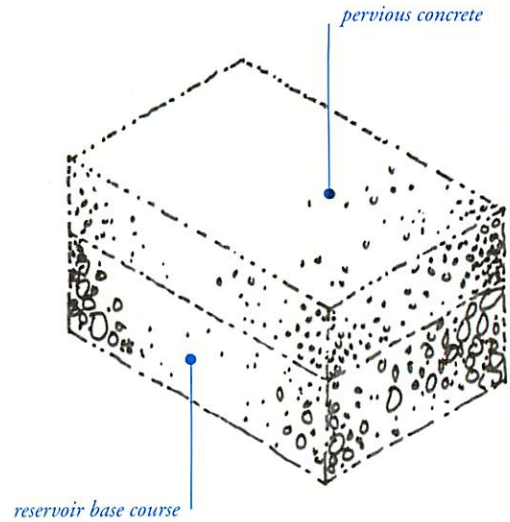
Legend ○ Least ◗ ● Most

	Cost (initial)	Cost (maint.)	Effectiveness	OK in clay†
5.1 Permeable pavements				
Conventional asphalt/concrete	◗	○	○	●
5.1a Pervious concrete	●	●	●	○
5.1b Porous asphalt	●	●	●	○
5.1c Turf block	◗	●	●	◗
5.1d Brick	●	◗	◗	◗
5.1e Natural stone	●	◗	◗	◗
5.1f Concrete unit pavers	◗	◗	◗	◗
5.1g Gravel	○	◗	●	●
5.1h Wood mulch	○	◗	●	●
5.1i Cobbles	○	◗	◗	●
5.2 Residential streets				
Conventional street standards	●	●	○	●
5.2a Street hierarchy	○	○	●	●
5.2b Access street: urban neo-traditional standard	○	○	●	●
5.2c Access street: rural standard	○	◗	●	●
5.2d Urban curb/swale system	◗	◗	●	◗
5.2e Rural swale system	○	◗	●	◗
5.2f Concave median	○	○	●	◗
5.2g Cul-de-sac streets	○	○	●	◗
5.3 Parking lots				
Conventional parking lot	○	◗	○	◗
5.3a Hybrid parking lot	○	◗	●	●
5.3b Parking grove	◗	○	●	●
5.3c Overflow parking	○	◗	●	●
5.3d Grass swale	◗	◗	◗	◗
5.3e Subsurface runoff storage	●	●	●	●
5.4 Driveways				
Conventional driveway	○	◗	○	●
5.4a Not directly-connected driveway	○	○	●	◗
5.4b Gravel driveway	○	◗	●	●
5.4c Unit pavers on sand	●	◗	◗	◗
5.4d Paving only under wheels	○	◗	●	●
5.4e Flared driveways	○	○	●	●
5.4f Temporary parking	○	◗	●	●
5.5 Buildings				
Conventional pipe system to curb	●	◗	○	●
5.5a Dry-well	○	◗	●	◗
5.5b Cistern	●	◗	◗	●
5.5c Foundation planting	○	○	●	◗
5.5d Permeability near buildings	◗	○	●	◗
5.6 Landscape				
Conventional pipe system to curb	●	◗	○	●
5.6a Plant selection and landscape maintenance	○	○	●	●
5.6b Concave vegetated surfaces	○	○	●	●
5.6c Multiple small basins	◗	◗	●	●
5.6d Bio-retention area	◗	◗	●	●

† Details are indicated suitable for clay if they either reduce DCIA or can be designed as retention/detention systems.

Details

5.1 *Permeable pavements*



5.1a Pervious concrete

5.1 Permeable pavements. Permeable pavements are a method of infiltrating stormwater while simultaneously providing a stable load-bearing surface. While forming a surface suitable for walking and driving, permeable pavements also contain sufficient void space to infiltrate runoff into the underlying reservoir base course and soil. In this way they can dramatically reduce impervious surface coverage without sacrificing intensity of use.

There are three main categories of permeable pavements: poured-in-place pervious concrete and porous asphalt, unit pavers-on-sand, and granular materials.

All of these permeable pavements (except turf block) have in common a reservoir base course. This base course provides a stable load-bearing surface as well as an underground reservoir for water storage. The base course must meet two critical requirements:

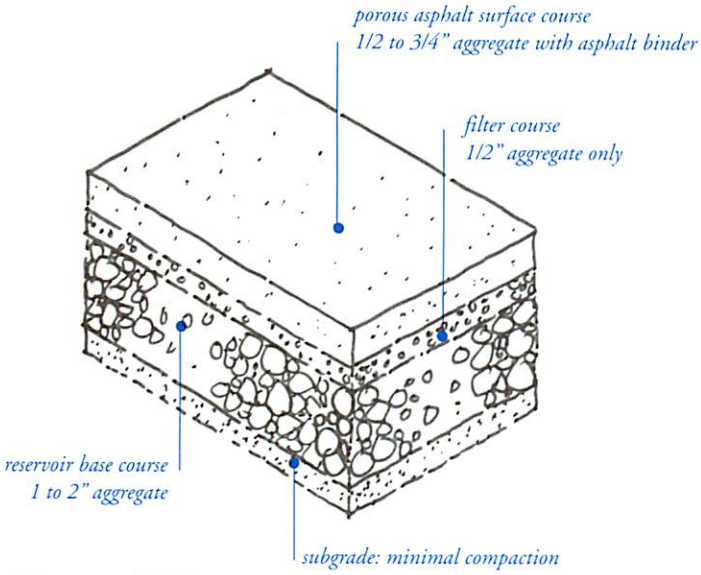
- it must be *open graded*, meaning that the particles are of a limited size range, so that small particles do not choke the voids between large particles. Open-graded crushed stone of all sizes has a 38 to 40% void space, allowing for substantial subsurface water storage.[19]

- it must be *crushed stone*, not rounded river gravel. Rounded river gravel will rotate under pressure, causing the surface structure to deform. The angular sides of a crushed stone base will form an interlocking matrix, allowing the surface to remain stable.

Pervious concrete and porous asphalt are two emerging paving materials with similar properties. Like their impervious, conventional counterparts, both make a continuous, smooth paving surface. They differ from their conventional counterparts in that they allow water to pass through the surface course to the rock base course that serves as a reservoir and infiltration basin for stormwater. Both pervious concrete and porous asphalt share similar design considerations.

5.1a Pervious concrete. Pervious concrete, also known as Portland cement pervious pavement, is most commonly used in Florida, where it was developed in the 1970s. Pervious concrete is a discontinuous mixture of coarse aggregate, hydraulic cement and other cementitious materials, admixtures, and water, which forms a permeable pavement.

Pervious concrete, like other concretes, acts as a rigid slab. It has an appearance very similar to exposed aggregate concrete, and provides a similar walking or riding surface. An aggregate base course can be added to increase total pavement thickness or



5.1b Porous asphalt
(adapted from City of Rockville, MD. specifications)

hydraulic storage. Pervious concrete is an extremely permeable material: in tests by the Florida Concrete and Products Association, permeability of new surfaces has been measured as high as 56 inches per hour, with improper installation or mix, permeability can be reduced to 12 inches per hour. Even after attempts to clog the surface with soil by pressure washing, the material retained some permeability.[20] Because of its porosity, pervious concrete pavements usually do not require curbs and gutters for primary drainage control.

5.1b Porous asphalt. Porous asphalt consists of an open-graded asphalt concrete over an open graded aggregate base, over a draining soil. Unlike traditional asphalt concretes, porous asphalt contains very little fine aggregate (dust or sand), and is comprised almost entirely of stone aggregate and an asphalt binder, giving it the common name "popcorn mix." Without fines filling the voids between the larger particles, porous asphalt has a void content of 12 - 20%, making it highly permeable.

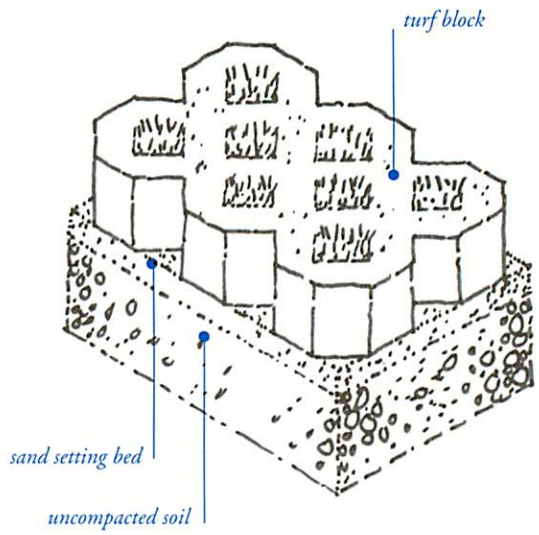
Porous asphalt is used by Caltrans as a wearing course on freeways because its porosity creates a superior driving surface in rainy weather. These installations are always over an impermeable asphalt layer and are not permeable pavements.[21]

In installations where porous asphalt has been used over a permeable base, the pavement becomes an infiltration system, allowing water to pass through the surface and collect in the open-graded aggregate base, achieving stormwater management without use of curbs or gutter systems. In these sites, mostly parking lots and light duty roads in the eastern United States, permeability has been maintained over long periods without special maintenance. The oldest porous asphalt pavement in the United States, at the University of Delaware Visitors' Center, was built in 1973, and is still permeable and structurally sound after 23 years.[22]

On light duty streets built of porous asphalt, some loss of porosity occurs in localized areas due to sedimentation or scuffing at intersections due to repeated wheel turning, but the overall performance of the pavement is not significantly compromised.[23]

Pervious concrete and porous asphalt design considerations: Sealing and clogging of the pavement surface is possible, even with vigorous maintenance and high power vacuuming. Most successful installations of pervious concrete and porous asphalt are in Florida and other coastal areas where slopes are flat, soils sandy, and winter sanding/salting minimal. Avoid installation in high traffic areas, and stabilize surrounding land to minimize sediment deposition on the pavement.

Permeable pavements (continued)



5.1c Turf block

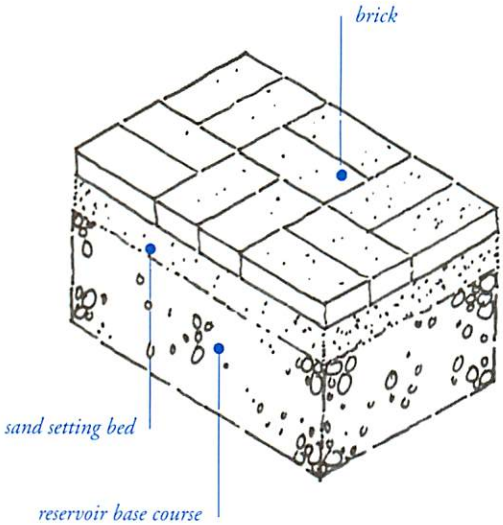
Installation must meet special requirements. Subgrade uniformity is essential, and slopes over a few percent are not recommended because of potential subgrade erosion. A permeable base and an infiltration rate of at least 0.5 inches/hour in the native soil is required (i.e. a HSG A or B soil).

Installation of pervious concrete and porous asphalt requires special tools and has narrower tolerances than traditional concretes or asphalts. Finally, lack of independent testing (especially in the case of pervious concrete) limits the ability to make judgements about long-term performance.

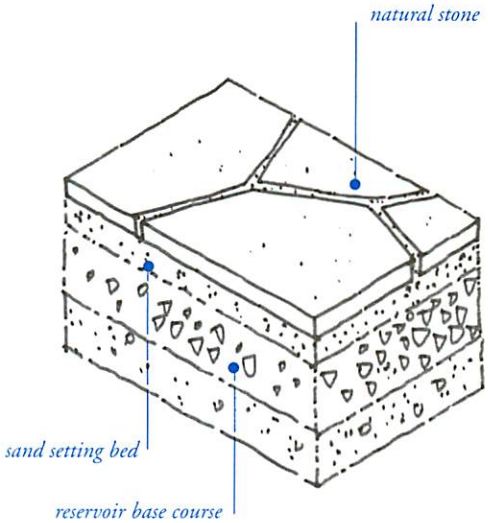
Unit costs of these permeable pavements are greater than traditional concrete and asphalt, though this additional cost can be offset by savings realized from not building a curb and gutter drainage system. Potentially a valuable means of reducing impervious land coverage in applications requiring a large, smooth pavement, their relative unfamiliarity, special requirements and lack of conclusive testing have made pervious concrete and porous asphalt little used in the San Francisco Bay Area to date. If these materials begin to gain wider local acceptance, their relative costs will likely go down.

Unit pavers-on-sand. A wide variety of unit pavers are readily available for use in outdoor applications. Unlike poured-in-place concretes or asphalts, which create one continuous surface, unit pavers made of discrete units that are set in a pattern on a prepared base. This gives unit pavers great flexibility in design, construction, and maintenance. *Open-celled unit pavers* are designed to create a permeable pavement surface, allowing water to pass through precast voids. *Solid unit pavers,* made of impermeable materials, can produce permeable pavement surfaces if they are spaced to expose a permeable joint and set on a permeable base. Unit pavers are available in a wide variety of colors, shapes, and textures. Sometimes colored concrete is stamped to appear like unit pavers, but this pavement surface performs both hydrologically and structurally like a poured concrete slab, and does not provide the stormwater infiltration opportunities of unit pavers-on-sand.

5.1c Turf block. Turf block is one example of an open celled unit paver. These open celled unit pavers are available in both precast concrete or plastic, and are often filled with soil and planted with turf. They were first developed in Germany in the 1960s to reduce the "heat island" effect of large parking areas and are now widely used throughout the world. The products vary in size, weight, surface characteristics, strength, durability, interlocking capabilities, proportion of open area per grid, run-



5.1d Brick



5.1e Natural stone

off characteristics, and cost. Laboratory tests have shown that open celled unit pavers have runoff coefficients (see box) of from 0.05 to 0.35, depending on slope, and surface configuration.[24]

When planted with turf, they are generally most successful in overflow parking areas, driveways, or emergency access roads. If installed in heavily used parking areas the turf often does not get adequate sunlight, and on heavily traveled roadways it can be worn away from tire abrasion. Occasionally open celled unit pavers are filled with alternatives to turf, either an inert gravel or a lower maintenance groundcover such as chamomile, that can absorb some traffic. Because of their irregular surface, open celled unit pavers generally do not provide comfortable walking surfaces, though the degree of comfort varies depending on design.

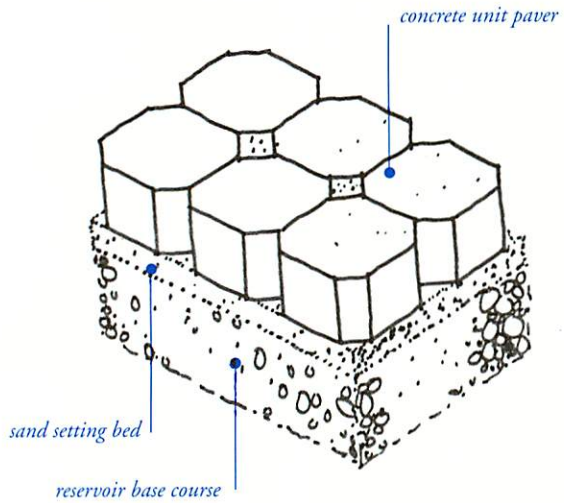
5.1d Brick. Clay fired brick is an ancient, solid paving material of great durability and flexibility. When laid on a permeable base with sand joints, brick paving provides an opportunity for a limited amount of stormwater infiltration, especially at low rainfall intensities. One experiment found coefficient of runoff volume to rainfall volume between 0.13 and 0.51 at half hour rainfall intensities up to 0.03 inches, increasing to between 0.66 and 0.76 at intensities between 0.06 and 0.12 inches per half hour.[25] The larger the joints, the greater the permeability.

Brick is available in a wide range of colors and finishes, and can be set in a variety of patterns. When laid on sand, it creates a very suitable walking or riding surface. Though it was widely used for roads in the early part of this century, it is today generally used for driveways, pathways, plazas, and patios.

Because brick is a relatively soft material, brick pavements can develop a rich character over time as the surface becomes slightly worn with use and the natural colors and textures are exposed. Brick is generally comparable in cost with other solid unit pavers, though shipping costs and special finishes or colors can affect price significantly.

5.1e Natural stone. Natural stone paving materials are available in a wide variety of shapes and colors. Because of their high cost and relative brittleness, they are usually laid in thin pieces on a mortar bed over concrete, making an impervious pavement. Some natural stone materials, such as flagstone and granite, are available in thicker slabs suitable for laying on sand. When laid in a random pattern with wide sand, gravel, or soil joints (from 1/2 to 4 inches) random cut stone can create a highly permeable pavement. The joints can be planted with small groundcovers or left bare. Smaller, square cut stones can also be made into permeable pavements. The cobblestone walks of older European cities are a familiar example of natural stone pave-

Permeable pavements (continued)



5.1f Concrete unit pavers

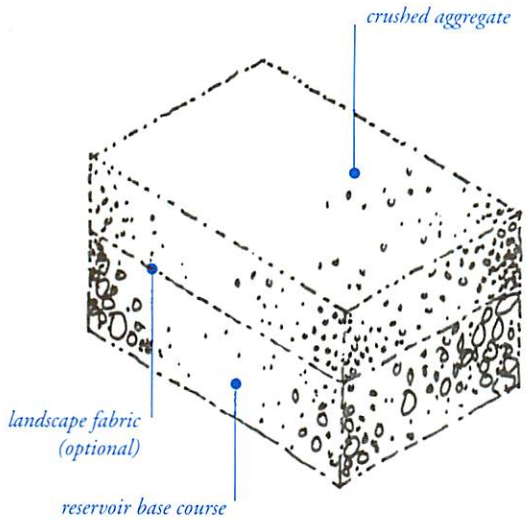
ment. Stones set in these tighter sand joints can be expected to have a permeability similar to brick-on-sand.

Because of their high cost natural stone pavements are generally limited to patio areas or walkways, where they can be extremely attractive. Some stone materials, such as flagstone and slate, are relatively brittle and suitable for pedestrian areas only. Paving made of harder stone, such as granite, can bear vehicular loads.

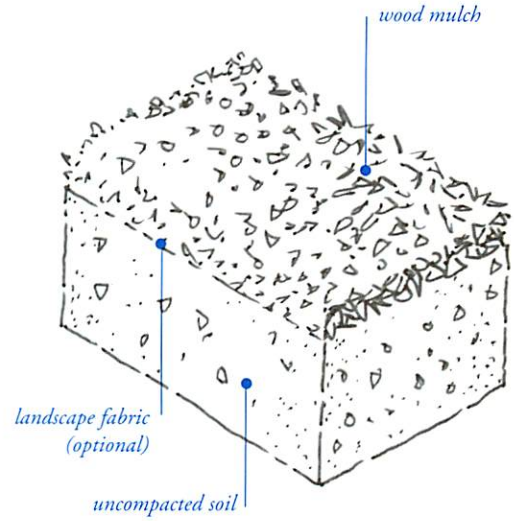
5.1f Concrete unit pavers. Solid precast concrete unit pavers are available in a wide variety of colors, shapes, sizes, and textures. They are designed to be set on sand, and form an interlocking pavement surface that can bear heavy traffic loads. Their permeability and performance is similar to brick-on-sand. Some manufacturers are now producing concrete unit pavers with small voids to increase permeability (e.g. "Ecostone"). The cost of concrete unit pavers is generally the lowest of all unit pavers, though it can vary depending on shipping, special colors or finishes.

Unit pavers-on-sand considerations. Installation costs for unit pavers on sand are higher than traditional asphalt or concrete paving. Unit pavers-on-sand, however, are generally less expensive to install than mortar-set unit pavers on a rigid concrete base, especially considering the added cost of drainage structures required for the mortared design. Solid unit pavers require no special maintenance, though the joints between units may require occasional weed supression, depending on the size of the joints, the subgrade, and other conditions. Grassed open-celled unit pavers require the same maintenance as lawns. Open-celled pavers filled with gravel require periodic "topping off" of the voids to replace gravel picked up by tire tread and pedestrians.

Unit pavers are especially valuable for walkable surfaces around trees, as they allow infiltration of water and air. If root growth causes the pavement surface to become uneven, the unit pavers can be removed and reset smoothly. Occasionally differential settlement can occur in a pavement made of unit pavers on sand, creating tripping hazard. This most often occurs if the base is improperly prepared, but can be remedied by recompacting the base and relaying the pavers. Penetration of mineral and organic particles into narrow sand joints of solid unit pavers-on-sand can severely limit permeability over time.



5.1g Crushed aggregate



5.1h Wood mulch

Granular materials. A wide variety of loose porous aggregates can be made to form permeable pavements suitable for walking, jogging, biking, or very light vehicular traffic. The size of these granular materials can range from fine aggregates to large stones, and can be divided into two general categories: gravels and cobbles. Depending on the size of the aggregate, these granular pavements have a runoff coefficient of 0.20 to 0.40.[24]

5.1g Crushed aggregate. A wide variety of crushed aggregates, generally known as gravel, can be used to form a permeable pavement. Aggregates are available in a variety of sizes, ranging from approximately 2" to sand sized grains known as "fines." Relatively inexpensive to purchase and easy to install, gravel can be laid in any shape or configuration. To keep aggregates confined to its desired area, it is generally laid in a field that is bounded by some rigid frame such as wood header, metal edging or concrete banding. Many colors, grades, and type of parent material are available, including crushed decomposed granite, base rock, and pea gravel. In selecting gravel pavements for pedestrian or vehicular traffic, crushed stones provide the most suitable surface, as the angled facets of the aggregate form an interlocking, semi-rigid matrix. Naturally worn small stones, such as pea gravel, have smooth round surfaces which rotate under pressure, making for a less firm footing.

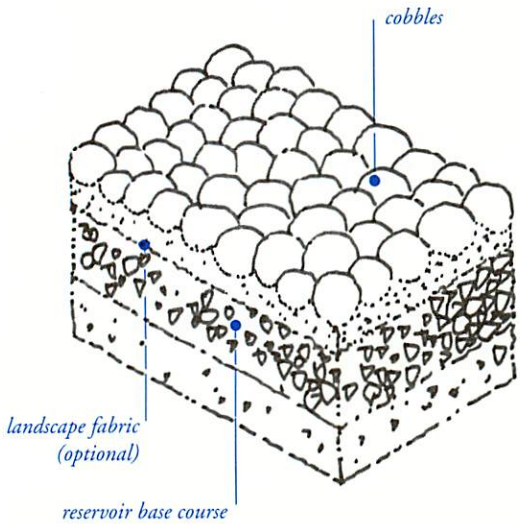
For surfaces subject to vehicular use, crushed gravel sizes between 3/8" and 3/4" make a stable surface that is also easy to walk on.

Found in a variety of settings ranging from Parisian cafes to Japanese ceremonial gardens to rural roadways, crushed aggregate is a versatile, economical permeable pavement material with a long history of use.

5.1h Wood mulch. Wood mulches and wood chips are among organic granular materials that can be used as permeable surfaces suitable for light pedestrian use. Some of these mulches meet federal requirements for playground fall surfaces, and can be inexpensive, safe, permeable pavements for outdoor play areas.

5.1i Cobbles. Larger granular materials are known as cobbles. Cobble sizes generally range from approximately 6" to 24" diameter and are available in a variety of stones and colors. Cobbles do not make a very suitable surface for walking or vehicular traffic, but are especially useful as a permeable pavement in areas where little traffic is desired, such as under large trees, or in hard to maintain areas such as median islands.

Permeable pavements (continued)



5.1i Cobbles

Cobbles have similar construction characteristics as gravel, except they are somewhat more labor intensive to install because each cobble must generally be set individually.

Granular materials considerations. If laid on a moderate slope, and subjected to moderate traffic or concentrated runoff, loose gravel surfaces can be displaced and require periodic regrading. Organic materials such as bark or wood chips decompose over time and must be replenished. Weed abatement may be required periodically, though this can be minimized by laying a permeable landscape fabric between the gravel and subgrade layers. In general, installation costs for gravel and other granular materials are the least of all permeable pavements, but all require a degree of periodic maintenance to preserve the integrity of the pavement surface.

Concrete and asphalt. Conventional concrete and asphalt (technically known as **portland cement concrete** and **asphaltic concrete**, respectively) are impervious pavements widely used in site development. Because of their ease of installation, flexibility, durability, economy, and load bearing capabilities, concrete and asphalt are the most commonly used standard pavement materials. With a runoff coefficient of near 1.0, conventional concrete and asphalt pavements are principal contributors to impervious land coverage in most residential development.

In site design for stormwater quality, these materials are best used sparingly. If more permeable pavement materials cannot be used, minimizing the area of concrete and asphalt surfaces through clustering and other techniques will reduce the resulting impervious land coverage. For the area that remains, designing asphalt and concrete pavement surfaces to slope towards infiltration basins instead of into directly-connected collection structures will minimize their negative impact on water resources.

Details

5.2 *Residential streets*

A typical pre-war street

28 foot wide with tree-lined parkway between the curb and sidewalk. This traditional design can be found in older neighborhoods throughout the Bay Area.

A typical post-war street

36 foot wide with no parkway between sidewalk and curb. Note how few vehicles occupy the street, even though a great deal of area is paved.

5.2 Residential streets. Residential streets are at the nexus of a wide variety of land use and environmental issues. An understanding of their scope, history, and function helps to explain their central importance in the design of residential development for stormwater quality.

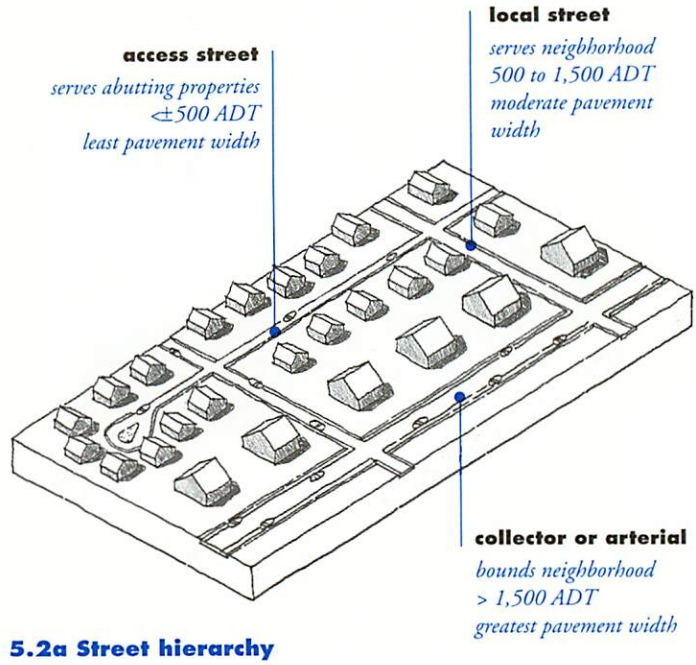
Considered a number of ways, the street is a large design element. In a typical residential neighborhood, the public right-of-way – the street – comprises approximately 20 to 25% of total land area, making it the single most important determinant of neighborhood character. Streets also can comprise up to 70% of a community's total impervious land coverage, with the remainder of impervious land coverage from rooftops and other structures. This makes street design the single greatest factor in a residential development's impact on environmental quality. Finally, because the street exists in the public right-of-way, it comprises nearly 100% of public open space in a typical residential community. Because it is located in the public right-of-way, it is subject to municipal ordinances, standards, and management, giving local jurisdictions a great deal of control over street design. For these reasons, the street is the single most important design element in residential site planning, and the element that can be most directly affected by local ordinances and policies.

Prior to World War II, traditional residential streets were designed as multiple use spaces, shared by pedestrians, children at play, animals, and low volumes of vehicular traffic traveling at low speed. The prototypical residential subdivision, laid out by Frederick Law Olmsted at Riverside, Illinois, in 1869, has 24 feet wide streets with concrete curb and gutter, lined with broad 12 foot wide parkway strips planted with trees. Outside of the parkway strip is a 5 foot wide sidewalk on both sides.[25] This model was copied all over the United States, and many pre-war neighborhoods can be found today with similar traditional street geometries.

After World War II, new street standards were developed to facilitate the automobile, which was growing both in dominance and number. Standards set by professional associations such as the Institute of Transportation Engineers (ITE) and the American Association of State Highway and Transportation Officials (AASHTO) as well as rules promulgated by the Federal Housing Administration increased paved area by up to 50% compared to pre-war designs, setting typical residential street width at 36 feet, plus curb, gutter and 5 feet of sidewalk on both sides.[26] These standards were applied in communities throughout the Bay Area and the United States. For ease of maintenance, many communities abandoned the parkway strip between the curb and sidewalk, bringing the sidewalk flush with the back of the

Details

5.2 *Residential streets (continued)*



5.2a Street hierarchy

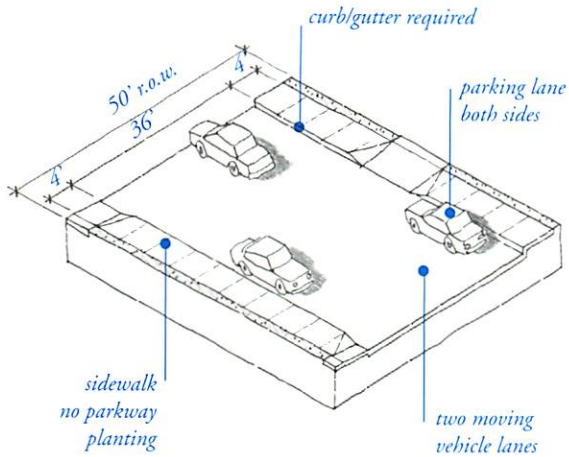
curb and eliminating the street trees. In a typical 50 foot wide right-of-way, this 46 foot wide standard pavement section (36 feet of street plus 10 feet of sidewalk) creates 92% impervious land coverage in the right-of-way. Compared to the inviting, park-like space of the original Olmsted model, with its 57% impervious land coverage (34 feet of pavement inside a 60 foot right of way), the modern residential street can be a hot, treeless place.

Today professionals from many fields, including transportation engineers, landscape architects, urban designers, and environmental scientists, are reevaluating residential streets with the intent of creating new standards that are more hospitable and that are more environmentally responsible. New street standards based on the pre-war models (known as "neo-traditional design") are now being studied and adopted in municipalities across the country. At the national professional level, a technical committee of the ITE is currently considering neo-traditional street standards that permit local streets between 22 and 30 feet wide, allowing parking on both sides, with or without curbs.

5.2a Street hierarchy. Municipal standards generally classify street widths by the planned function of the street: local, collector or arterial. *Local streets*, the smallest class, are intended to provide access to abutting properties, and have a typical average daily traffic (ADT) of less than 1,500 vehicles. Through traffic and truck traffic is generally discouraged on local streets. *Collector streets* are an intermediate class, intended to collect traffic from local streets and deliver it to larger arterial streets. They also can serve as the primary traffic route within a residential or commercial area, and have a typical ADT between 1,500 and 3,000. Finally, the largest class (except highways and freeways), *arterial streets,* have an ADT between 3,000 and 10,000, and are intended to provide long distance travel, with controlled intersections and higher speeds. For residential design, local streets are most relevant.

A survey of Bay Area municipalities reveals that the **typical current standard** for a two-way local street with parking on both sides requires two moving lanes, plus two parking lanes, plus curb, gutter and sidewalks each side, making a total of 40 to 50 feet of pavement within a typical 50 foot right-of-way (see table).

Yet, the number of vehicle trips on a local street can vary considerably, depending on the number of abutting dwelling units. Given the generally accepted rule-of-thumb for residential street design of 10 vehicle trips per day per dwelling unit, a street with ten single family homes can be expected to generate an ADT of 100, or an average of one vehicle trip approximately every 15



Typical current standard for a local street:

90±% impervious land coverage

minutes (every 6 minutes in the peak hour). In comparison, a local street serving one hundred homes (1,000 ADT) will generate an average of one vehicle trip every 90 seconds (every 30 seconds in the peak hour). When built to typical municipal standards, the two mandated moving lanes of a local street uses a great deal of land area for very little traffic. If the street is considered in terms of space, rather than lanes, a central space wide enough for one vehicle can be retained for movement, with parking and waiting space along both sides. In the infrequent instance when two vehicles approach in opposite directions, one vehicle can pull into the parking lane to allow the other vehicle to pass in the central moving space. The many driveway openings on either side of the street ensure than at any given segment of the street some space will be available for waiting, even if parking spaces are full on both sides. On lightly traveled streets, the minor inconvenience of waiting for oncoming traffic does not occur very often, making a shared central moving space feasible for streets serving up to 50 dwelling units (500 ADT, one vehicle every 3 minutes average, every 1.5 minutes peak).[27]

Unlike most municipal standards, which set street width by number of vehicle lanes and roadway classification (local, collector, arterial), street design by anticipated traffic volumes (ADT) allows for varying pavement width to match usage. Using the

Impervious land coverage and street design standards.

Most Bay Area municipal street standards mandate over 80% impervious land coverage in the public right-of-way. Alternative standards can significantly reduce impervious land coverage while meeting access needs of local, residential streets.

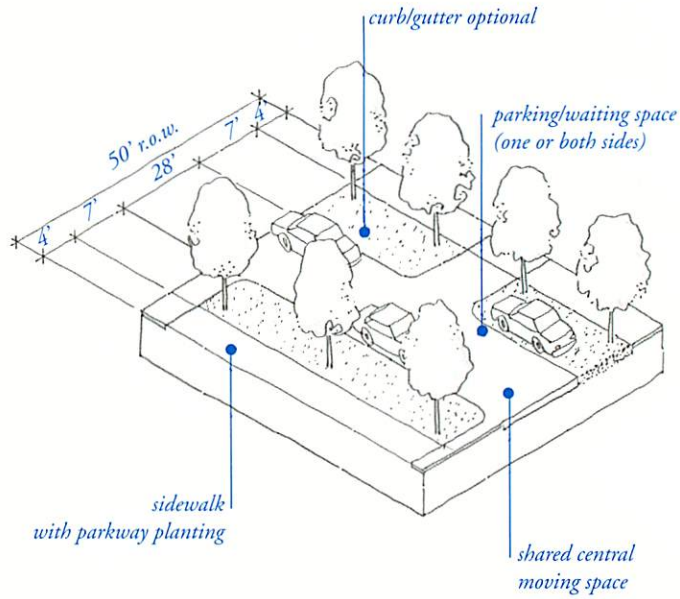
Representative local street standards for Bay Area municipalities.

Jurisdiction	Street width	curb/gutter required	sidewalk required	parkway planting	r.o.w. imper.
Alameda Co.	40 ft.	yes	5'/side	no	100%
Concord	36	yes	4'/side	varies	90%
Contra Costa Co.	32	yes	4'/side	no	78%
Palo Alto	40	yes	4'/side	yes	85%
San Jose (std.)	35	yes	5'/side	no	100%
San Mateo Co.	36	yes	4'/side	no	94%
Alternative street standards for local and access streets.					
Neotraditional	28±	no	4'±	yes	74%
Rural	20±	no	no	yes	36%
San Jose (alt.)†	30	yes	4'/side	yes	81%

(All standards reflect minor or local street standards for flat areas to accommodate two way traffic, with parking both sides, typical right-of-way between 45 and 60 feet wide.)

† San Jose Narrow Residential street standard, parking one side only.

Residential streets (continued)



5.2b Access street: urban neo-traditional standard

74± % impervious land coverage

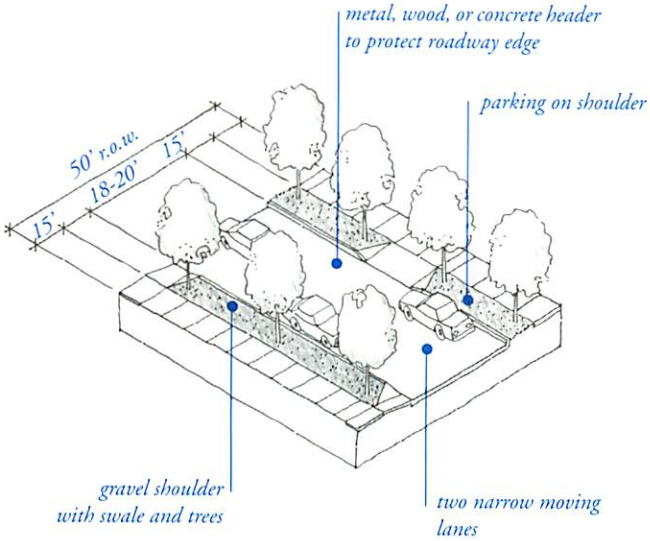
analogy of stream flow, this "headwaters streets" system allows the most "upstream" streets, those serving approximately 50 adjacent dwelling units, to have widths as low as 16 feet while allowing two-way traffic. As traffic volumes increase on neighborhood streets, pavement widths also increase, just as streams widen downstream to accommodate increased water volumes.[28] In practice this generates a new class of street for very low traffic volumes, referred to as "access" streets, which are below "local" street in the standard street hierarchy.

For example, an access street serving 50 single family homes (25 each side) with 50 foot width lots would require 1,250 linear feet of street ((50 sfh/2) x 50 ft = 1250). A 36 foot wide street would cover 45,000 square feet, usually in impervious asphalt or concrete pavement. A 26 foot wide street would cover 32,500 square feet, a reduction of 12,500 of impervious land coverage. Assuming street construction costs of $10 per square foot, this reduction in pavement generates a $125,000 reduction in development costs, or $2,500 per lot. This does not account for added cost reductions in reduced need for drainage systems because of smaller impervious land coverage. Even greater reductions in pavement can be achieved if on-street parking is not required on both sides the entire length of the street, or if sidewalks are not required on both sides.

Two types of access streets can be built using neo-traditional standards: rural or urban.

5.2b Urban neo-traditional standard. An urban standard will utilize curbs and gutters, though the gutter may be tied to a biofilter or swale rather than an underground storm drain. According to an informational report published by the Institute of Transportation Engineers (ITE), pavement widths for neo-traditional urban streets are typically from 26 to 30' wide with a shared central moving lane, and parking permitted on one or both sides. Sidewalks are provided on at least one side of the street, though usually preferable on both sides.[29]

5.2c Rural Standard. A rural standard can be used where aesthetics and other factors permit, with curbs and gutters replaced by gravel shoulders, further reducing construction costs and improving opportunities for stormwater infiltration. The gravel shoulders are graded to form a drainage way, with opportunities for infiltration basins, ponding and landscaping. A narrow two-lane paved roadway is provided, approximately 18 to 22 feet wide. Most of the time single vehicles use the center of the paved roadway. When two cars are present moving in opposite directions, drivers reduce speeds and move towards the right hand shoulder. Protection of the roadway edge and organization of parking are two issues in rural street design. Roadway



5.2c Access street: rural standard

36± % impervious land coverage

edge protection can be achieved by flush concrete bands, steel edge, or wood headers. Parking can be organized by bollards, trees, or allowed to be informal. On very low volume, low speed, access streets, sidewalks may not be required, as pedestrians walk in the street or on the shoulder.

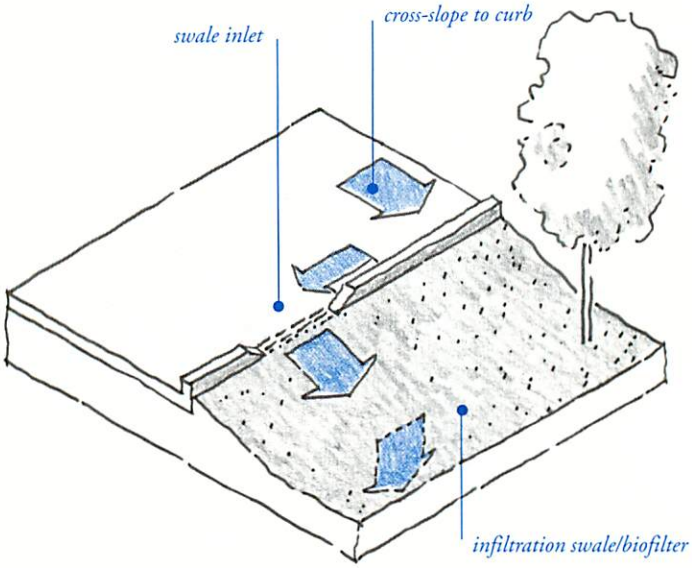
The current typical municipal street standards that mandate 80 to 100% impervious land coverage in the public right-of-way are a principal contributor to the environmental degradation caused by residential development. A street standard that allows a hierarchy of streets sized according to average daily traffic volumes yields a wide variety of benefits: improved safety from lower speeds and volumes, improved aesthetics from street trees and green parkways, reduced impervious land coverage, less heat island effect, and lower development costs. If the reduction in street width is accompanied by a drainage system that allows for infiltration of runoff, the impact of residential streets on stormwater quality can be greatly mitigated.

Street width considerations. The experience of both the pre-war traditional streets and newer subdivisions of neo-traditional design has shown that low volume streets with shared moving lanes can be safe, often safer than wider streets, because drivers are more cautious. These neo-traditional streets are designed for traffic speeds between 15 to 25 mph, compared to a design speed of 30 mph for most current municipal standards.[30] This reduced design speed increases safety, particularly for pedestrians. Nevertheless, shared moving space may promote unsafe conditions or high incidences of driver inconvenience if traffic volumes are much above 500-750 ADT. On access streets where bicycle traffic is especially high, such as designated bike routes or in university towns, wider streets may be advisable to provide adequate space.

Emergency service providers often raise objections to reduced street widths. Typical Fire Department standards require greater moving space for emergency access than accommodated by neo-traditional designs. A principal concern is that emergency access may be blocked if a vehicle becomes stalled in the single moving lane. Grid street systems provide multiple alternate emergency access routes to address this concern, though there may be a marginal increase in response times. Documenting the number of instances where delay has occurred in existing pre-war neighborhoods with street widths below current Fire Department standards may be a suitable way to asses the risk of this situation arising in new neighborhoods with neo-traditional street design, and to balance it with the demonstrated increased risk from higher traffic speeds on wider streets.

Emergency service access is one factor of many that form a general assessment of neighborhood safety. Some ways to balance

Residential streets (continued)



5.2d Urban curb/swale system

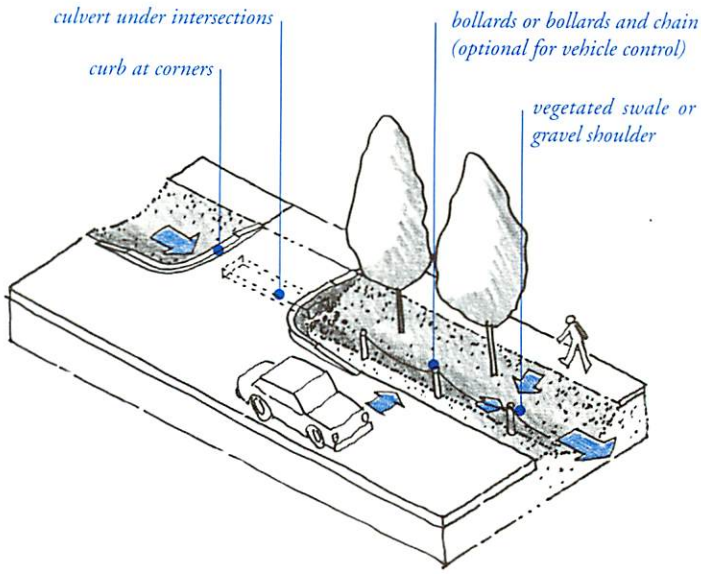
emergency service access with the benefits of access streets include: allowing parking on one side only to preserve a wider moving space and requiring smoke alarms or sprinkler systems to reduce fire hazards.

Hillside sites have special access concerns and fire risks. Because of the potential of shared moving lanes to be blocked by a single vehicle, with no comparable alternate route, reduced street widths may not be advisable on long cul-de-sac streets or narrow hillside sites.

Street drainage. Current Bay Area municipal standards generally require concrete curb and gutter along both sides of a residential street, regardless of number of houses served. The curb and gutter serves several purposes: it collects stormwater and directs it to underground conveyance drainage systems, it protects the pavement edge, it prevents vehicle trespass onto the pedestrian space, it provides an edge against which street sweepers can operate, and it helps to organize on-street parking.

For stormwater quality, curb and gutter systems act to collect and concentrate pollutants, providing a directly connected conduit to natural water bodies. There are two alternatives to typical curb and gutter systems that meet functional requirements while lessening the street's impact on stormwater quality.

Inlet detail for urban curb/swale system
Just as a drop inlet collects runoff into an underground pipe system, a swale inlet collects runoff into a surface infiltration system. This swale inlet includes boulders set in soil to dissipate flow velocities and minimize erosion.



5.2e Rural swale system

5.2d Urban curb/swale system. On streets where a more urban character is desired, or where a rigid pavement edge is required, curb and gutter systems can be designed to empty into drainage swales. These swales can run parallel to the street, in the parkway between the curb and the sidewalk, or can intersect the street at cross angles, and run between residences, depending on topography. Runoff travels along the gutter, but instead of being emptied into a catch basin and underground pipe, multiple openings in the curb direct runoff into surface swales or infiltration/detention basins. If planted with turfgrass and gently sloped, these swales function as biofilters (see Drainage systems 4.1c). Because concentration of flow will be highest at the curb opening, erosion control must be provided, which may include a settlement basin for ease of debris removal.

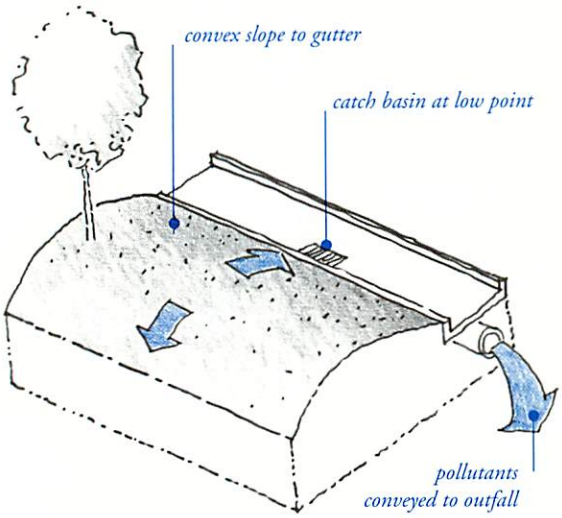
5.2e Rural swale systems. On streets where a more rural character is desired, concrete curb and gutter need not be required. Since there is no hard edge to the street, the pavement margins can be protected by a rigid header of steel, wood or a concrete band poured flush with the street surface. Parking can be permitted on a gravel shoulder. If the street is crowned in the middle, this gravel shoulder also can serve as a linear swale, permitting infiltration of stormwater along its entire length. Because runoff from the street is not concentrated, but dispersed along its entire length, the buildup of pollutants in the soil is minimized. If parking is not desired on the shoulder, or if it needs to be organized, bollards, trees or groundcovers can be installed along the shoulder to prevent vehicle trespass.

In these ways edge treatments other than continuous concrete curb and gutters with underground drainage systems can be integrated into street design to create a headwaters street system that minimizes impact on stormwater quality and that captures the most attractive elements of traditional neighborhood design.

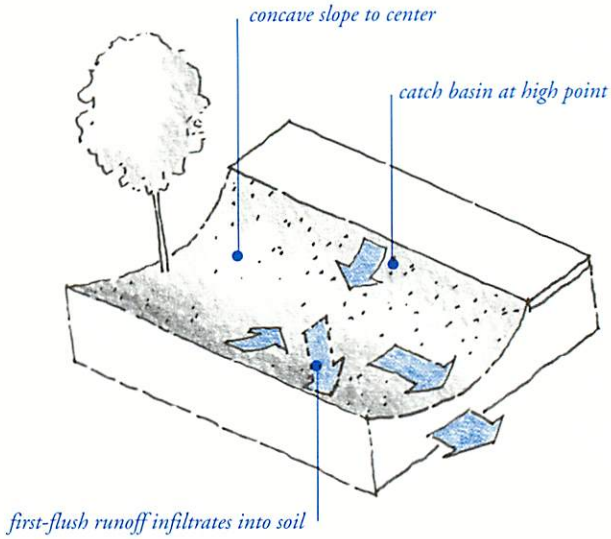
Street drainage considerations. The perception that surface swale systems require a great deal of maintenance is a barrier to their acceptance. In practice, maintenance is required for all drainage systems, and surface systems can require comparable or less maintenance than underground systems. Design factors for low maintenance include:

- erosion control at curb openings
- shallow side slopes and flat bottoms (as opposed to ditches which erode)
- planting with easily maintained groundcover such as turf
- minimizing weeds through proper plant selection or installation of permeable landscape fabric.

Residential streets (continued)



Conventional median design: convex surface



5.2f Alternative concave median

Maintenance practices for surface systems are different than most urban Public Works Departments currently practice, and some employee retraining may be required to facilitate maintenance of street systems using surface swales instead of concrete curbs and underground pipes. One advantage of surface drainage systems is that problems, when they occur, are easy to fix because they are visible and on the surface.

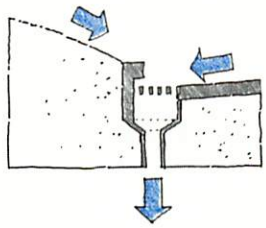
Medians. Sometimes streets are designed with central medians to divide traffic for safety or aesthetics.

Conventional median design includes a convex surface rising above the pavement section, with drainage directed towards a curb and gutter system. Runoff is conveyed rapidly off the median and the street directly into a catch basin/underground pipe system, concentrating pollutants and carrying them to water bodies.

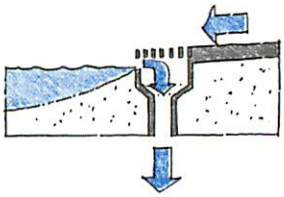
5.2f Alternative concave median. If the soil level in the median is designed as a concave surface slightly depressed below the pavement section, water is directed from the street into the median.

Concave medians are especially valuable at treating the first-flush runoff, which carries a high concentration of oils and other pollutants off the street, especially if the median is designed as a landscaped swale or turf lined biofilter. Because of the relatively small area provided by the median for stormwater infiltration and retention, a catch basin and underground storm drain system may be required. By setting catch basin rim elevations just below the pavement elevation, but above the flow line of the infiltration swale, a few inches of water will collect in the swale before overflowing into the underground system.

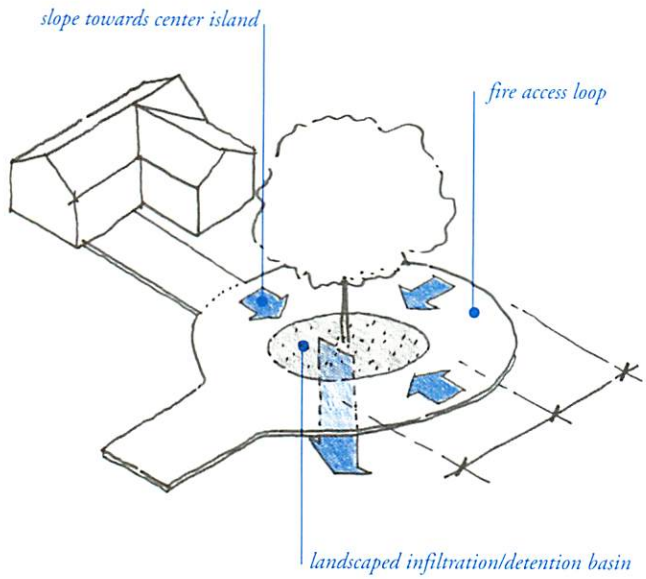
Catch-basin design for medians.



A catch basin located at the low point of a *conventional convex median* and gutter collects all runoff – including the first flush.



Like an overflow drain in a bathtub, a catch basin located just below the pavement surface, and a few inches above the flow line of a *concave median*, provides an opportunity to pond runoff while also providing drainage for larger storms.



5.2g Cul-de-sac streets

5.2g Cul-de-sac streets. Cul-de-sac streets present special opportunities and challenges. Because cul-de-sac streets terminate, they require a turn-around area large enough to accommodate large trucks, such as occasional moving vans and emergency access vehicles. Fire departments, in particular, often require 60 feet or greater diameter turnarounds. If an entire 60 foot diameter turnaround is paved, it creates an 11,000 square foot impervious circle, or $^1/_4$ acre of impervious land coverage. Aside from the implications for stormwater quality, this is especially unfortunate as a design element, because it creates an unattractive heat island at the front of several homes.

A turnaround with a central concave landscaped space can meet fire department access requirements and also create an opportunity for stormwater infiltration or detention. A landscaped area in the center of a cul-de-sac can reduce impervious land coverage 30 to 40%, depending on configuration. Design of a landscaped cul-de-sac must be coordinated with fire department personnel to accommodate turning radii and other operational needs.

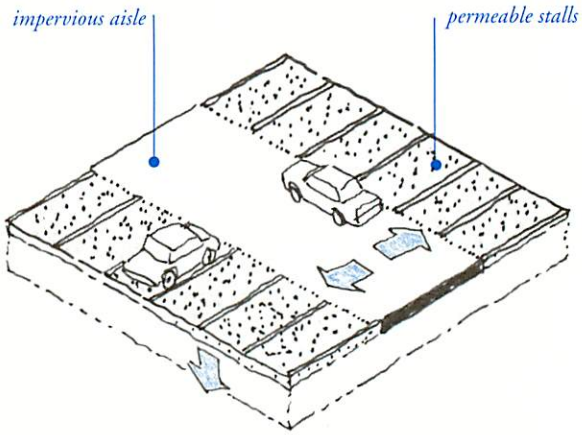
General considerations for residential street design. Alternative standards are feasible for local residential streets that employ "neo-traditional" or "headwaters street" design. These alternative standards can reduce impervious land coverage and provide drainage systems with less impact on stormwater quality compared to current typical municipal street standards, while accommodating local traffic and emergency access.

Street designs are often controversial, and development of new street standards must meet a variety of engineering, public safety and functional criteria. Municipal agencies with a strong interest in street design, such as Public Works, Planning, and emergency service providers, often differ on priorities and approaches. Alternative standards must be developed cooperatively so that each agency's legitimate interests are accommodated. In municipalities which have not adopted alternative standards, developers can propose these designs as part of a planned unit development zoning, subject to government approval.

Several communities in the United States have recently adopted new street standards for local access streets, including Bucks County, PA., Boulder, CO., Portland, OR, and San Jose, CA.[31] These new municipal street standards vary, but they all include reduced street widths (generally between 16 and 30 feet), shared moving lanes, reduced design speeds, and an ability to omit curbs, gutters and/or sidewalks on one or both sides. New ITE neo-traditional street design standards currently in review may help formalize acceptable alternative residential street designs.[32]

Details

5.3 *Parking lots*



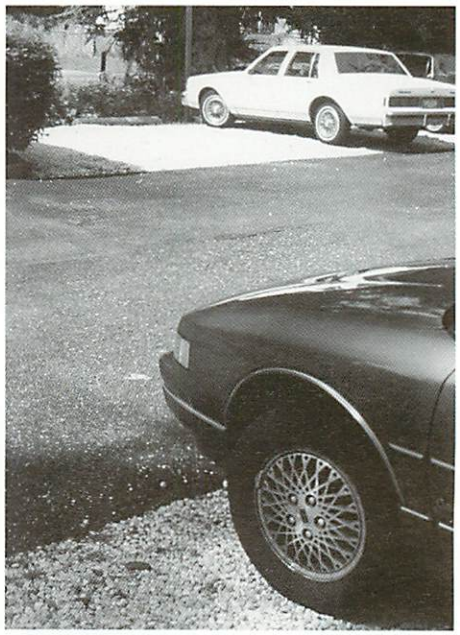
5.3a Hybrid lot.

Parking lots. In any development, storage space for stationary automobiles can consume many acres of land area, often greater than the area covered by streets or rooftops. In a neighborhood of single family homes, this parking area is generally located on private driveways or along the street. In higher density residential developments, parking is often consolidated in parking lots.

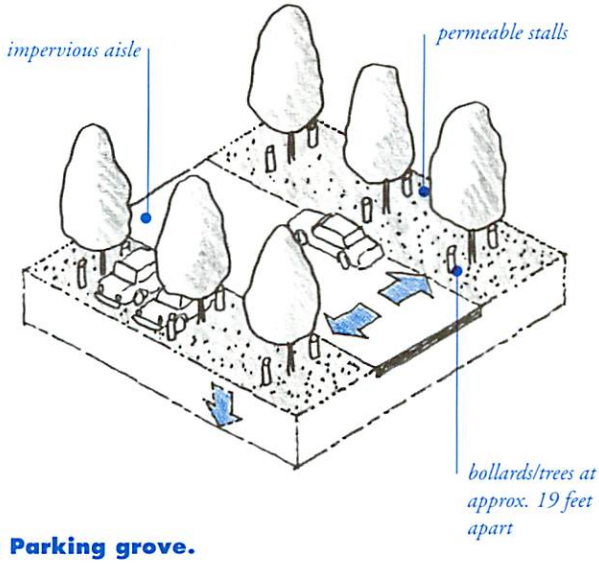
The space for storage of the automobile, the standard parking stall, occupies only 160 square feet, but when combined with aisles, driveways, curbs, overhang space, and median islands, a parking lot can require up to 400 square feet per vehicle, or nearly one acre per 100 cars. Since parking is usually accommodated on an asphalt or concrete surface with conventional underground storm drain systems, parking lots typically generate a great deal of directly-connected impervious area.

There are many ways to both reduce the impervious land coverage of parking areas and to filter runoff before it reaches the storm drain system.

5.3a Hybrid lot. Hybrid lots work on the principle that pavement use differs between aisles and stalls. Aisles must be designed for speeds between 10 and 20 mph, and durable enough to support the concentrated traffic of all vehicles using the lot. The stalls, on the other hand, need only be designed for the 2 or 3 mph speed of vehicles maneuvering into place. Most of the time the stalls are in use, vehicles are stationary. Hybrid lots reduce impervious surface coverage in parking areas by differ-



Hybrid parking lot.
This hybrid lot in a mixed-use development in Medford Village, N.J. uses crushed aggregate parking stalls and a conventional asphalt aisle.
(photo: Bruce Ferguson)



5.3b Parking grove.

entiating the paving between aisles and stalls, combining impervious aisles with permeable stalls.

If the aisles are constructed of a more conventional, impermeable material suitable for heavier vehicle use, such as asphalt, the stalls can be constructed of a permeable pavement. This can reduce the overall impervious surface coverage of a typical double-loaded parking lot by 60%, and avoid the need for an underground drainage system.

Permeable stalls can be constructed of a number of materials, including crushed aggregate, open-celled unit pavers, porous asphalt, or pervious concrete (see Permeable Pavements, 5.2). A hybrid lot of crushed aggregate stalls and conventional asphalt aisles is a low-cost, practical design that is easily constructed from standard materials (see photo, previous page). In most cases, stall markings are not required, as the geometry of the edges promotes orderly parking. If desired, stalls can be indicated with wood headers, change in unit paver color, or pavement markers ("botts dots").

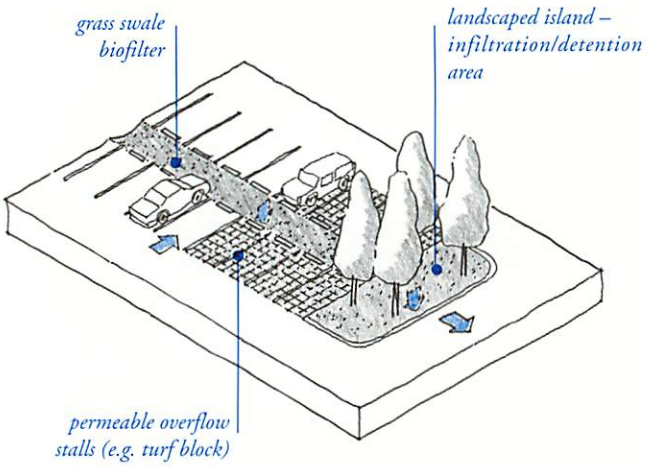
5.3b Parking Grove. A variation on the permeable stall design, a grid of trees and bollards can be used to delineate parking stalls and create a "parking grove." If the bollard and tree grid is spaced approximately 19 feet apart, two vehicles can park between each row of the grid. This 9.5 foot stall spacing is slightly more generous than the standard 8.5 to 9 foot stall, and allows for the added width of the tree trunks and bollards. A benefit of this design is that the parking grove not only shades parked cars, but presents an attractive open space when cars are absent.

Parking Grove.

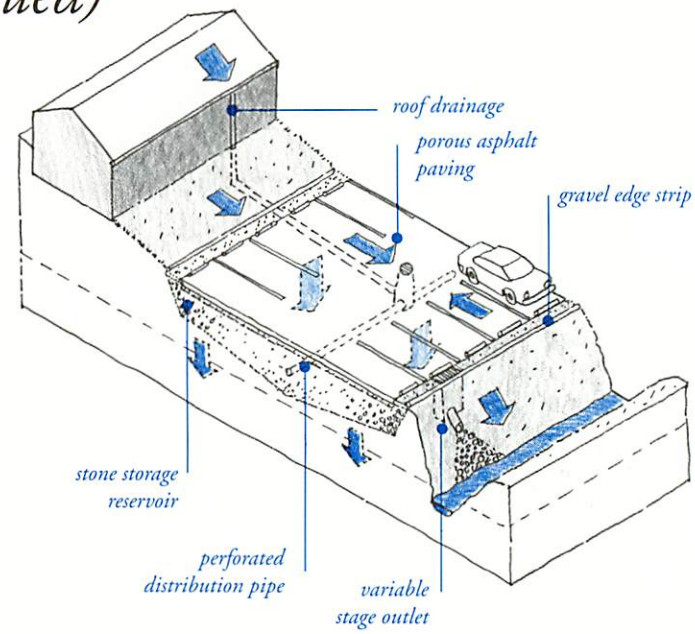
This parking grove at a Seaside, FL. hotel uses bollards and trees at approximately 10 ft. on center to create a shady courtyard that accommodates parking. The crushed oyster shell pavement is permeable and stable for walking and driving.

Details

5.3 *Parking lots (continued)*



5.3c/d Overflow parking and landscaped areas.



5.3e Subsurface stormwater storage
(adapted from Prince Georges Co., MD)

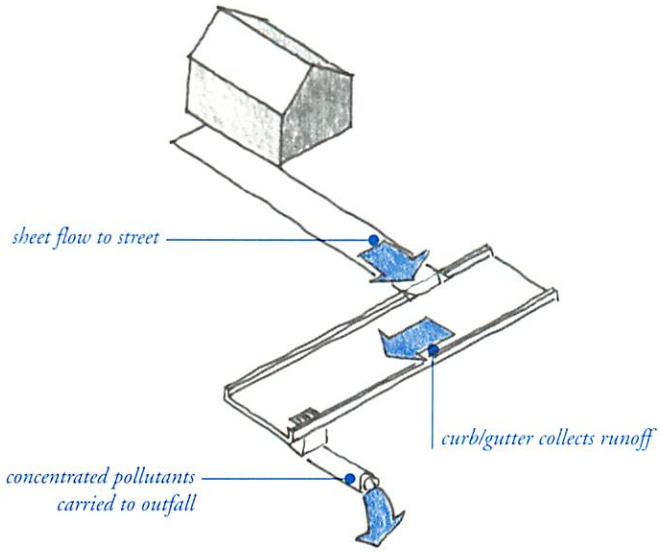
5.3c Overflow parking. In some locations daily parking needs fluctuate, often with peak use occurring only for special events or seasons. Typically, parking lots must be constructed to accommodate the peak demand, generating a high proportion of impervious land coverage of very limited usefulness.

An alternative is to differentiate between regular and peak parking demands, and to construct the peak parking stalls of a different, more permeable, material. This "overflow parking" area can be made of a turf block, which appears as a green lawn when not occupied by vehicles, or crushed stone.

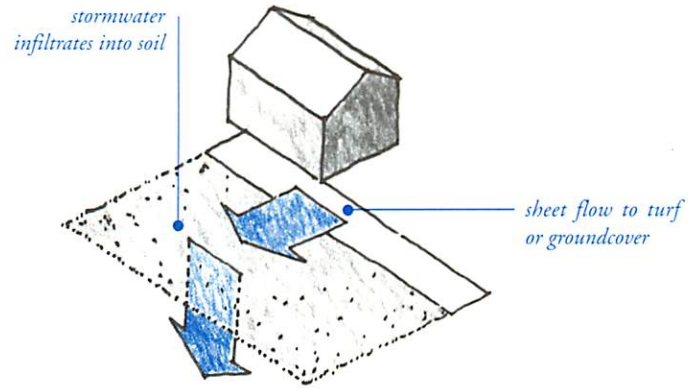
5.3d Grass swales and landscape islands. Parking lot drainage can be integrated with landscaping to provide infiltration and detention basins. Grass swales can be a particularly effective design strategy in large conventionally paved parking lots, by providing, low maintenance, walkable, linear biofilters along the perimeter of the lot or along internal islands. Other landscape treatments are also feasible, but may require additional matinenance effort. Stormwater is directed to these linear landscaped spaces and travels slowly over turfgrass or other vegetated surfaces, allowing pollutants to settle and slowing runoff velocities (See 4.1c biofilters).

5.3e Subsurface stormwater storage. In some cases parking lots can be designed to perform more complex stormwater management functions. Subsurface stormwater storage and infiltration can be achieved by constructing a stone-filled reservoir below the pavement surface and directing runoff underground by means of perforated distribution pipes. Subsurface infiltration basins eliminate the possibilities of mud, mosquitoes and safety hazards sometimes perceived to be associated with ephemeral surface drainage. They also can provide for storage of large volumes of runoff, and can be incorporated with roof runoff collection systems. These underground infiltration and storage systems are relatively expensive, and required extensive engineering, but have been used in a variety of locations in the eastern United States where land values are high and need to control runoff is great.[33]

Details 5.4 *Driveways*



Directly-connected impervious driveway.
A conventional driveway that is a "directly connected impervious area" drains directly to the storm drain system – collecting and concentrating pollutants.



5.4a Not directly-connected impervious driveway

5.4 Driveways. Driveways can comprise up to 40% of the total transportation network in a conventional residential development, with streets, turn-arounds and sidewalks comprising the remaining 60%.

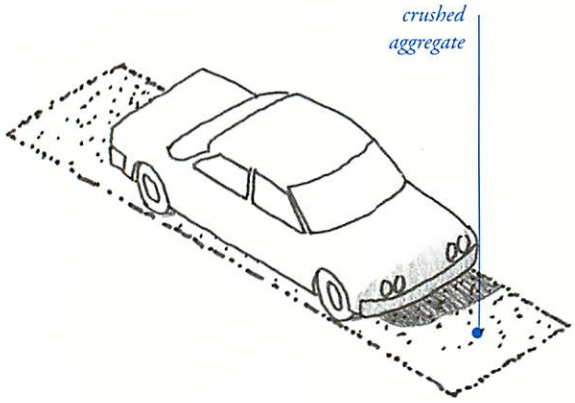
Driveway length is generally determined by garage setback requirements, and width is usually mandated by municipal codes and ordinances. If garages are set back from the street, long driveways are required, unless a rear alley system is included to provide garage access. If parking for two vehicles side-by-side is required, a 20 foot minimum width is required. Thus, if a 20 foot setback and a two-car wide driveway are required, a minimum of 400 square feet of driveway will result, or 8% of a typical 5,000 square foot residential lot. If the house itself is compact, and the driveway is long, wide, and paved with an impervious material such as asphalt or concrete, it can become the largest component of impervious land coverage on the lot itself.

Municipalities can reduce the area dedicated to driveways by allowing for tandem parking (one car in front of the other). Also, if shared driveways are permitted, then two or more garages can be accessed by a single driveway, further reducing required land area. Rear alley access to the garage can reduce driveway length, but overall impervious surface coverage may not be reduced if the alleys are paved with impervious materials and the access streets remain designed to conventional municipal standards.

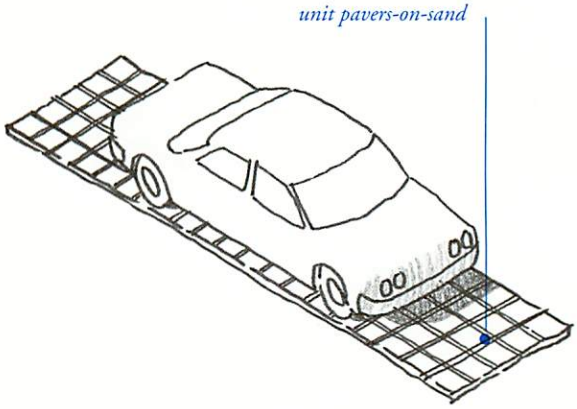
5.4a Not directly-connected impervious driveway. The easiest way to reduce the impact of a conventional impervious driveway on water quality is to slope it to drain into an adjacent turf or groundcover area. By passing driveway runoff through a permeable landscaped area, pollutants can be dispersed and cleansed in the soil. A conventional impervious driveway directly connected to the storm drain network collects and concentrates pollutants in subsurface runoff.

5.4b Gravel driveway. Gravel and other granular materials can make a suitable permeable pavement for driveways especially those that serve single family homes. Because it is lightly used by very slow moving vehicles, a well-constructed driveway of granular material can serve as a relatively smooth pavement with minimal maintenance. In choosing a granular material for a gravel driveway, crushed stone aggregate such as 3/8" to 3/4" granite is more suitable than rounded stones such as pea gravel, because the angles of the crushed stone form a matrix that holds the granular material in place. For proper infiltration and stormwater storage, the aggregate must be open-graded (see 5.1 Permeable pavements).

Driveways (continued)



5.4b Gravel driveway

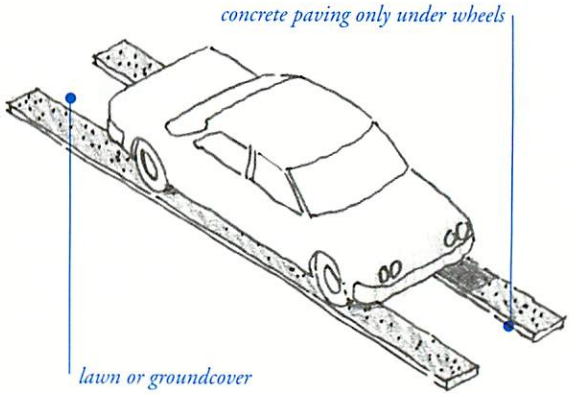


5.4c Unit pavers on sand

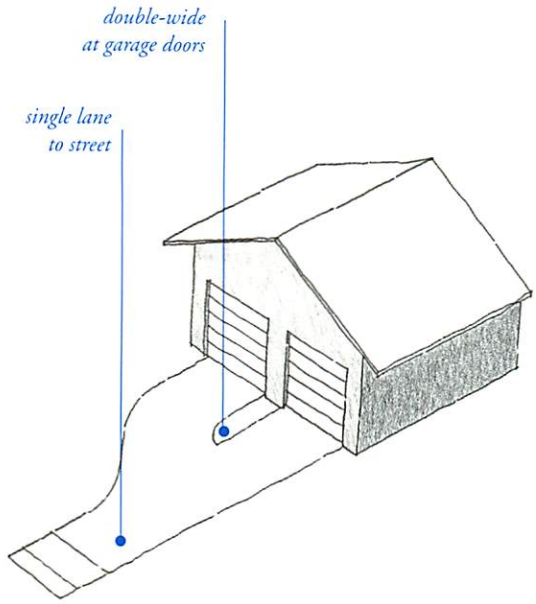
5.4c Unit pavers on sand. Unit pavers on sand can make a permeable, attractive driveway. A pavement of brick-on-sand or turf-block can make the drive way more integrated with the garden rather than an extension of the street penetrating deep into the garden space.

5.4d Paving only under wheels. Concrete paving only under the wheel tracks is a viable, inexpensive design if the driveway is straight between the garage and the street. By leaving the center strip open to be planted with grass, groundcovers or filled another permeable material such as gravel, a driveway of two concrete wheel tracks can reduce impervious surface coverage by 60 to 70% compared with a single lane concrete driveway.

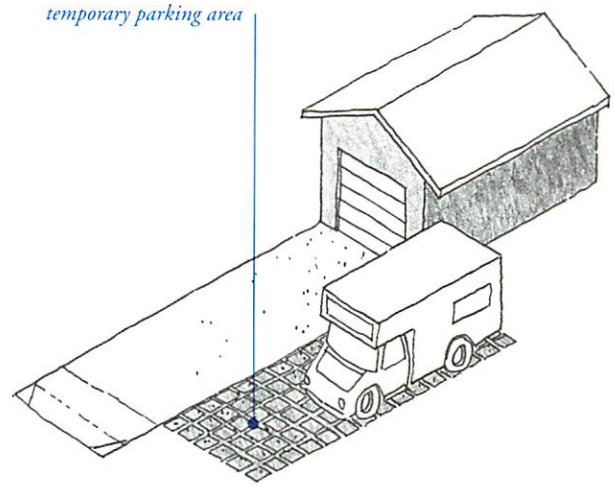
5.4e Flared driveways. Driveways that serve multi-car garages do not require the full multi-lane width along their entire length. The approach to the garage can be a single lane, adequate to accommodate the relatively infrequent vehicle trips, while the front of the garage can be flared to provide access to all garage doors. This strategy can reduce overall pavement cost and land coverage while maintaining adequate access for all parking spaces.



5.4d Paving only under wheels



5.4e Flared driveways



5.4f Termporary parking

5.4f Temporary parking. In some areas, parking or access is required infrequently. These areas can be paved with a permeable turf-block or similar paver, and maintained as a landscaped surface. For the majority of the time when it is not used for parking, it appears and functions as a green space. When needed for parking or access, the surface supports vehicle loads. This is an especially valuable strategy for emergency access routes or overflow parking.

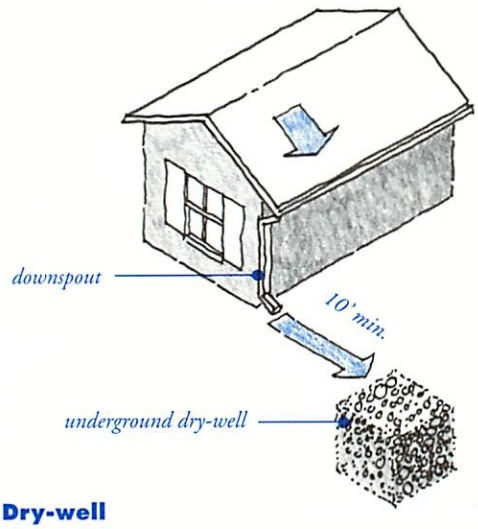
Driveway considerations. Driveways offer a relatively simple opportunity to improve both the aesthetics and permeability of residential developments.

By allowing tandem parking, shared driveways, or rear alley access, municipalities can minimize mandated driveway requirements.

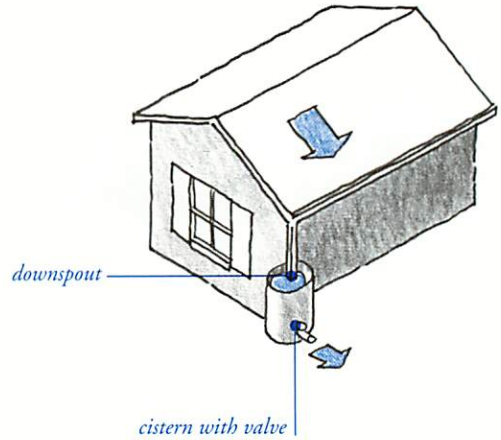
For designers and developers, the driveway's intimate relationship with the residence, and its relative freedom from government regulation, make it an element that can be designed to increase permeability and market appeal.

Some treatments, such as turf-block or gravel, require greater maintenance than poured-in-place asphalt or concrete designs. Other materials, such as brick or unit pavers, require a greater initial expense. Both the maintenance and cost implications of these designs can be balanced by the improved aesthetic and market appeal of driveways made from more attractive, more permeable pavements.

Details 5.5 *Buildings*



5.5a Dry-well



5.5b Cistern

5.5 Buildings. By definition, buildings create impervious land coverage. There are a limited number of techniques for treating runoff from individual buildings to collect rooftop runoff and allow it to infiltrate into the soil.

5.5a Dry-well. If a gutter and downspout system is used to collect rainwater that falls on a roof, runoff becomes highly concentrated. If the downspout is connected to a dry-well, this runoff can be stored and slowly infiltrated into the soil. A dry-well is a subsurface basin to which runoff is diverted for infiltration.

A dry-well is constructed by digging a hole in the ground and filling it with an open graded aggregate, such as no. 2 or 3 stone. An underground connection from the downspout conveys water into the dry well, allowing it to be stored in the voids. To minimize sedimentation from lateral soil movement, the sides and top of the stone storage matrix must wrapped in a permeable filter fabric, though the bottom may remain open. A perforated observation pipe (such as a 6" diameter PVC) can be inserted vertically into the dry-well to allow for inspection and maintenance.

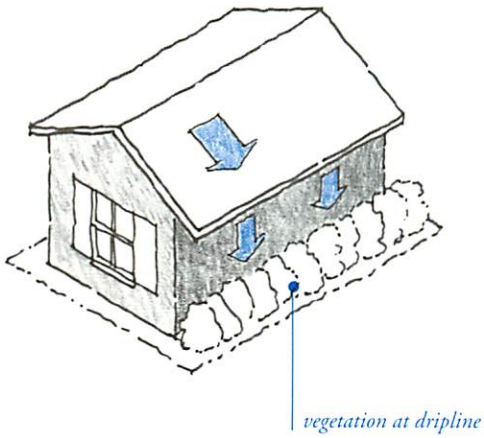
In practice dry-wells receiving runoff from single roof downspouts have been successful over long periods because they received very little sediment from their runoff source. They must be sized according to the amount of rooftop runoff received, but are typically 4 to 5 feet square, and 2 to 3 feet deep, with a minimum of 1 foot soil cover over the top, and a maximum depth of 10 feet.

To protect the foundation, they must be set away from the building at least 10 feet. Dry-wells must be installed in soils that accommodate infiltration, in poorly drained soils, dry-wells have very limited feasibility.

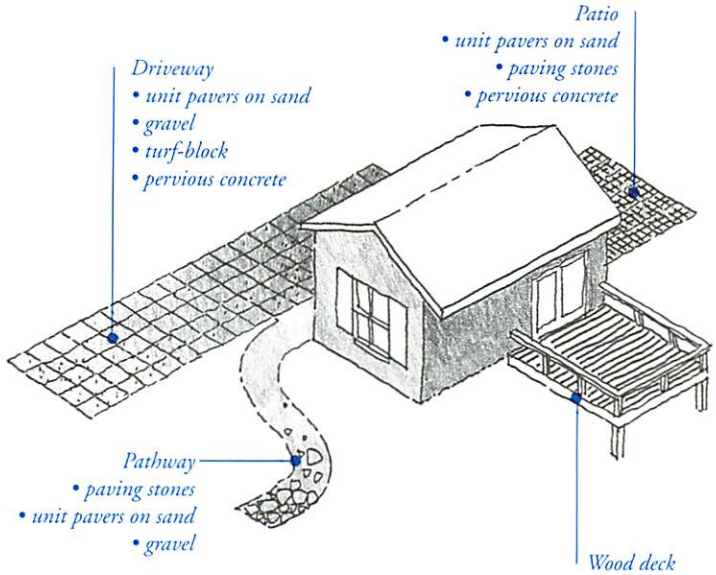
5.5b Cistern. Another way to store and slowly release roof runoff into the soil is to empty the downspout into a cistern. A cistern is an above ground storage vessel with either a manually operated valve or a permanently open outlet.

If the cistern has an operable valve, the valve can be closed to store stormwater for irrigation use or infiltration between storms. This system requires continual monitoring by the resident or grounds crews, but provides greater flexibility in water storage and metering. If a cistern is provided with an operable valve and water is stored inside for long periods, the cistern must be covered to prevent mosquitoes from breeding.

A cistern system with a permanently open outlet can also provide for metering stormwater runoff. If the cistern outlet is sig-



5.5c Foundation planting



5.5d Permeability near buildings

nificantly smaller than the size of the downspout inlet (say 1/4 to 1/2 inch diameter), runoff will build up inside the cistern during storms, and will empty out slowly after peak intensities subside. This is a feasible way to mitigate the peak flow increases caused by rooftop impervious land coverage, especially for the frequent, small storms.

Cisterns can be incorporated into the aesthetics of the building and garden. Japanese, Mediterranean and American southwest architecture provide many examples of attractive cisterns made of a variety of materials.

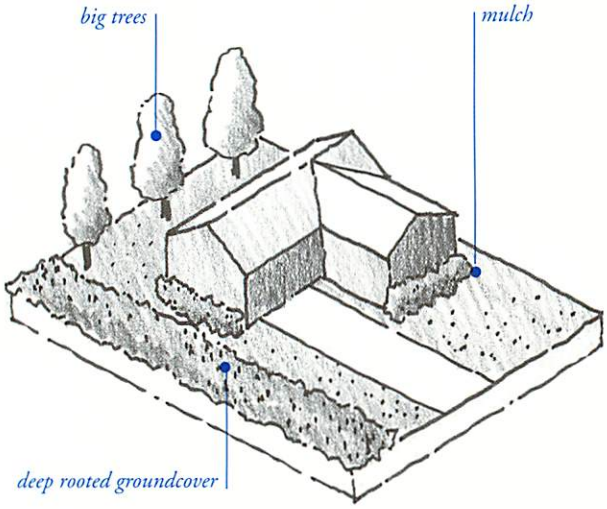
If a cistern holds more than 6" depth of water, it must be covered securely or have a top opening of 4" or less to prevent small children from gaining access to the standing water. The cistern must be designed and maintained to minimize clogging by leaves and other debris.

5.5c Foundation planting. For buildings that do not use a gutter system, landscape planting around the base of the eaves can provide increased opportunities for stormwater infiltration and protect the soil from erosion caused by concentrated sheet flow coming off the roof.

Foundation plantings can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration. These plantings must be study enough to tolerate the heavy runoff sheet flows, and periodic soil saturation.

5.5d Permeability near buildings. In addition to roof runoff collection strategies, a variety of permeable pavement materials can be utilized around residential buildings. This maximizes the opportunities for roof runoff to infiltrate into the soil and minimizes the impact of outdoor residential uses on stormwater quality.

Details 5.6 *Landscape*



5.6a Plant selection and landscape maintenance

5.6 Landscape. In the natural landscape, most soils infiltrate a high percentage of rainwater through a complex web of organic and biological activities that build soil porosity and permeability. Roots reach into the soil and separate particles of clay, insects excavate voids in the soil mass, roots decay leaving networks of macropores, leaves fall and form a mulch over the soil surface, and earthworms burrow and ingest organic detritus to create richer, more porous soil. These are just a few examples of the natural processes that occur within the soil.[34]

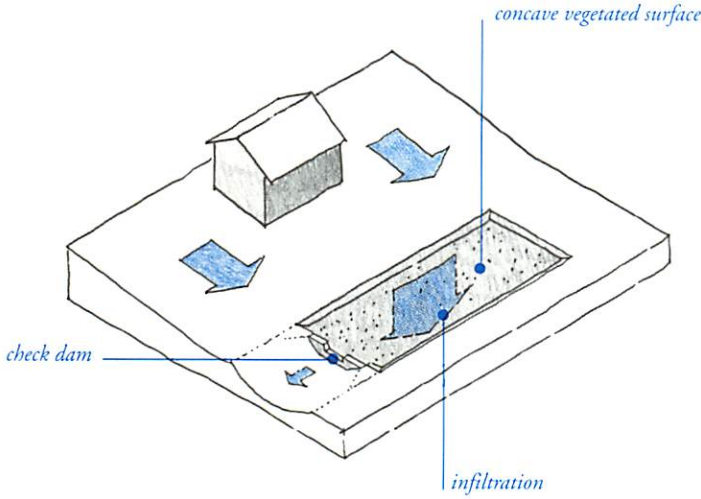
In development, a certain amount of soil must be covered with impervious surface, but the remaining landscape can be designed and maintained to maximize its natural permeability and infiltration capacity.

5.6a Plant selection and landscape maintenance. The proper selection of plant materials can improve the infiltration potential of landscape areas. Deep rooted plants help to build soil porosity. Plant leaf-surface area helps to collect rainwater before it lands on the soil, especially in light rains, increasing the overall water holding potential of the landscape. A single street tree can have a total leaf surface area of several hundred to several thousand square feet, depending on species and size. This above ground surface area created by trees and other plants greatly contributes to the water holding capacity of the land.

A large number of plant species will survive moist soils or periodic inundation. These plants provide a wide range of choices for planted infiltration/detention basins and drainage swales. Most inundated plants have a higher survival potential on well-drained alluvial soils than on fine-textured shallow soils or clays. Though oaks generally do not tolerate summer moisture, mature valley and blue oaks (*Quercus lobata* and *Q. douglasii*) in alluvial soils can survive winter inundation for up to 100 days annually.[35]

Maintenance can have a significant impact on soil permeability and its ability to support plant growth. Most plants concentrate the majority of their small absorbing roots in the upper 6 inches of the soil surface if the surface is protected by a mulch or forest litter. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches. The common practice of removing all leaf litter and detritus with leaf blowers creates a hard crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes.[36]

5.6b Concave vegetated surfaces. Landscape surfaces are conventionally graded to have a slight convex slope. This causes water to run off a central high point into a surrounding drain-



5.6b Concave vegetated surfaces

age system, creating increased runoff. If a landscape surface is graded to have a slightly concave slope, it will hold water. Conventional practice in a concave vegetated surface is to place an area drain or catch basin at the center to collect stormwater. If the drain is placed not in the central low spot, but at the high edge, just below the edge of adjacent pavements, then the concave surface will hold water until it reaches the level of the catch basin. This is similar to a bathtub with its center drain plugged – water fills the tub until just below its rim, where the overflow drain collects the rising water off the surface. In locations where a surface drainage system is utilized, a check dam can serve as an alternative to the overflow drain, allowing the water to overflow from the concave vegetated surface into a swale system.

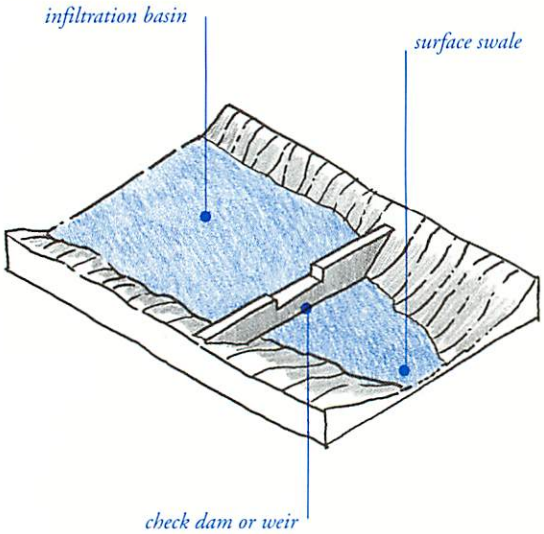
Concave vegetated surfaces need not be very deep to make a significant contribution to overall surface storage capacity and stormwater quality. For example, a square lawn area 50 feet on a side, sloping 2% towards the center will create a low point 6 inches below the outside rim. This 6 inch slope over 25 feet of distance is barely noticeable, and is similar to standard grading practice for lawn areas. This 50 foot x 50 foot x 6 inch deep lawn area creates a storage capacity of 413 cubic feet (volume = area of base x 1/3 altitude). If adjacent impervious surfaces, such as sidewalks, rooftops, and roads are designed to sheet drain into this concave lawn, their runoff can gradually infiltrate into the soil, removing and polishing pollutants. In a light rain, the concave lawn will gradually fill with water, storing runoff and allowing it to infiltrate gradually to roots and soil. In clay soils, these depressions can be designed as detention basins, to hold water for later release.

If a series of concave vegetated surfaces are designed and located to collect and hold runoff from small storms, most pollutants and stormwater can be controlled on-site. Catch basins located at the high edge of the concave vegetated surfaces collect cleaner runoff from larger storms and provide flood protection.

Because they have gently sloping sides and very shallow depths these concave vegetated surfaces pose minimal risk to the public. Because they are shallow and permeable, they hold water for only a few hours or days, and do not breed mosquitoes. When filled with water, concave vegetated surfaces reflect the sky, clouds, and leaves above, making an attractive landscape element.

5.6c Multiple small basins. Biofilters, infiltration and detention basins are the basic elements of a landscape designed for stormwater management (see Drainage system elements 4.4). The challenge for designers is to integrate these elements creatively and attractively in the landscape – either within a conventional landscape aesthetic, or by presenting a different land-

Landscape (continued)



5.6c Multiple small basins

scape image that emphasizes the role of water and drainage.

Multiple small basins can provide a great deal of water storage and infiltration capacity. These small basins can fit into the parkway planting strip or shoulders of street rights-of-way. If connected by culverts under walks and driveways, they can create a continuous linear infiltration system. Infiltration basins can be placed under wood decks, in parking lot planter islands, and at roof downspouts. Outdoor patios or seating areas can be sunken a few steps, paved with a permeable pavement such as flagstone or gravel, and designed to hold a few inches of water collected from surrounding rooftops or paved areas for a few hours after a rain.

All of these are examples of small basins that can store water for a brief period, allowing it to infiltrate into the soil, slowing its release into the drainage network, and filtering pollutants.

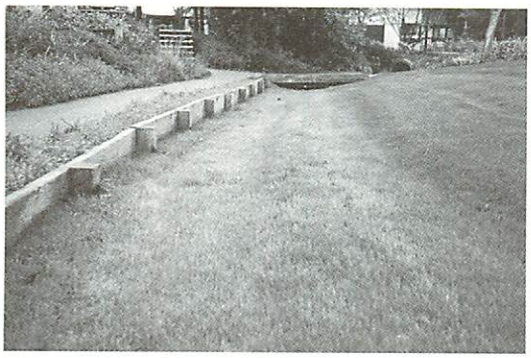
Landscape considerations. Landscape can perform a wide variety of stormwater management functions. In designing landscapes for stormwater management, appropriate groundcover must be selected. Turf grass lawns, woody perennials, and cobbles can all be used, depending on the desired aesthetic effect.

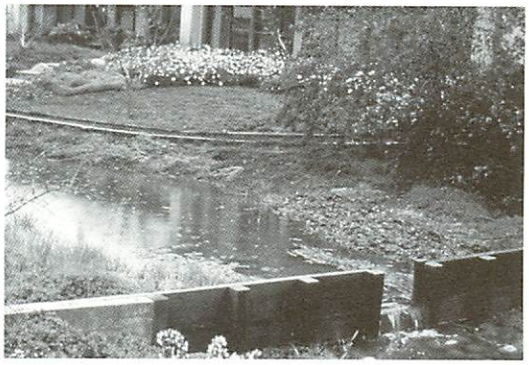
The infiltration value of concave vegetated surfaces is greater in permeable soils. Soils of heavy clay or underlain with hardpan may provide less infiltration value. In these cases concave vegetated surfaces must be designed as detention basins, with proper outlets for drainage into an interconnected system.

All landscape treatments require maintenance. Landscapes designed to perform stormwater management functions are not necessarily more maintenance intensive than highly manicured conventional landscapes. A concave lawn requires the same mowing, fertilizing and weeding as a convex one. Sometimes infiltration basins may require a different kind of maintenance than conventionally practiced.

Typical maintenance activities include periodic inspection of surface drainage systems to ensure clear flowlines, repair of eroded surfaces, adjustment or repair of drainage structures, soil cultivation or aeration, care of plant materials, replacement of dead plants, replenishment of mulch cover, irrigation, fertilizing, pruning and mowing.

When well maintained and designed, landscaped concave surfaces, infiltration basins, swales and bio-retention areas can add aesthetic value while providing the framework for an environmentally sound and comprehensive stormwater management system.





Basins for every landscape type.

An ordinary lawn.
This lawn presents a conventional landscape appearance – its role as an effective biofilter capable of holding a few inches of water is barely noticable.

A different landscape image.
This infiltration basin uses simple landscape materials to create a landscape of great diversity that accentuates its role in a surface drainage network.

Flood-tolerant trees

Most infiltration and detention basins are designed to remain inundated for less than 48 hours (drawdown time). The following trees tolerate wet soil and periodic innundation, and may be suitable for planting in basins and biofilters depending on climate zone and other factors. This list in not all-inclusive, and draws from both native and exotic species. Local riparian habitats may provide additional native species suitable for wet locations.

Acer negundo	Box Elder	*M. virginiana*	Sweet Bay
Acer rubrum	Red Maple	*Melaleuca quinquenervia*	Cajeput Tree
Acer saccharinum	Silver Maple	*Nyssa sylvatica*	Tupelo
Alnus spp.	Alder	*Picea sitchensis*	Sitka Spruce
Betula spp.	Birch	*Platanus x acerifolia*	London plane
Carya illinoensis	Pecan	*Platanus occidentalis*	Sycamore
Carya ovata	Buttonbush	*P. racemosa*	California Sycamore
Casuarina spp.	She-Oak	*Populus deltoides*	Cottonwood
Clethra arborea	Lily-of-the-Valley	*Pterocarya stenocarpus*	Wingnut
Cornus stolonifera	Redtwig Dogwood	*Quercus macrocarpa*	Bur Oak
Diospyros virginiana	Persimmon	*Q. palustris*	Pin Oak
Eucalyptus camalduensis	Red Gum	*Salix spp.*	Willow
E. citriodora	Lemon Gum	*Sequoia sempervirens*	Coast Redwood
E. erythrocorys	Red-Cap Gum	*Taxodium distichum*	Bald Cypress
Fraxinus latifolia	Oregon Ash	*Thuja occidentalis*	Arborvitae
Gleditsia triacanthos	Honey Locust	*Ulmus americana*	American Elm
Liquidambar styraciflua	Liquidambar	*Umbellularia californica*	California Bay
Liriodendron tulipifera	Tulip Tree	*Washingtonia robusta*	Fan Palm
Magnolia grandiflora	Southern Magnolia		

adapted from Harris (1992) and Sunset Western Garden Book (1988)

6 Case Studies

The concepts, site planning principles and design details described in the previous pages are integrated on the following pages in a series of case studies reflecting the diverse topography and market conditions of the Bay Area.

The case studies are illustrative. They show an approach to site planning and design that integrates stormwater management as an organizing element. Each of the details in Chapter 5 is illustrated at least once to show how the details work in combination with each other. Real sites, and real projects, will require unique combinations to suit unique conditions.

Site planning and design for residential development is a complex and demanding process. To be successful, a new residential development must meet marketing, economic, regulatory, engineering, environmental, construction, and design criteria. The following case studies attempt to show that by treating stormwater as a resource, and using it as a means to generate design, residential communities can be built that reward investment, are kind to the natural environment, and make better places for people to live.

Case Studies

Economic benefits of stormwater management

People have a strong emotional attachment to water, arising from its aesthetic qualities– tranquility, coolness and beauty. As a result, most waterbodies within developments can be used as marketing tools to set the tone for entire projects. A recent study conducted by the National Association of Home Builders indicates that "whether a beach, pond, or stream, the proximity to water raises the value of a home by up to 28 percent."[37]

In California's semi-arid climate, most of the techniques described in this document will not be year-round water features, but instead will hold water only during the rainy months. These ephemeral ponds and streams have a unique character, changing with the seasons and reflecting (literally) daily changes in weather.

Water features command a premium in the marketplace. Homebuyers and renters nation-wide demonstrate a willingness to pay a premium for properties adjacent to urban runoff controls that are designed with aesthetics in mind. According to the US E.P.A., land values for lots fronting runoff controls commanded 5 to 15% premiums over comparable lots at residential projects in Virginia, Colorado, Illinois and Kansas. In Davis, California, properties at Village Homes, a residential subdivision built in the late 1970s with seasonal swales and other environmental features, command significantly higher values than comparable homes in conventionally designed subdivisions.

Stormwater management for water quality presents developers with an opportunity to design more attractive projects that will have an advantage over conventionally designed competitors. Not only do subdivisions sell faster and at a premium, but development costs are generally lower for surface drainage systems compared to conventional underground systems.

Factors that lead to increases in property values. Urban runoff systems that appear to be natural systems are most effective at commanding increases in property values. If passive recreation is included (e.g. a walking path along a swale or playfield/ infiltration basin), an additional premium is realized. These recreational areas and wetlands can become a feature attraction when advertising the property. Amenities such as trails, gazebos, and bird houses may add costs, but these can be compensated for by faster sales and additional profits. Developers can charge premiums for properties with water views, stream frontage, access to greenbelts, or other amenities.

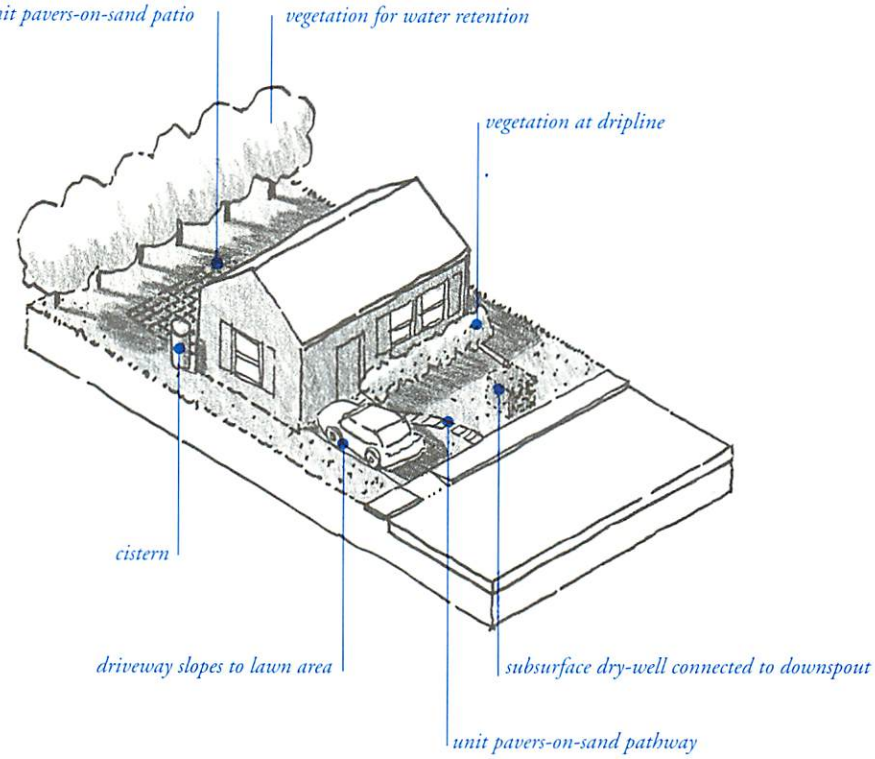
Maintenance. Proper maintenace of the drainage system is essential for homebuyer acceptance and marketing. Runoff controls that are poorly maintained can be a hazard or a nuisance. Maintenance costs need not be significantly higher than conventionally designed projects. For example, a concave lawn requires the same maintenance as a convex one, though the concave lawn can form part of a stormwater management system. In some designs, such as vegetated swales or seasonal ponds, periodic maintenance will be required, but it is less than other amenities routinely included in new development, such as fountains or tennis courts.

Green marketing. Many consumers today demonstrate a preference for products and services that are "environment friendly." Organically grown cotton clothing, natural foods, and recycled papers are a few of the products that sell at a premium to conventional competitors but command increasing market share. Homebuyers, too, respond to products that consciously promote more environmentally responsible designs, as long as these designs are safe, attractive and functional. By promoting a natural drainage system, developers can meet federal mandates for environmental quality while simultaneously differentiating their product through increased habitat, a more diverse landscape, and additional recreational opportunities.

This drainage swale, integrated with a pathway system and landscaping, makes an attractive recreational area that enhances property values.

Case Study

6.1 *Small single lot*



6.1 Small single lot. Even a small, single-family home lot can provide opportunities for stormwater management. Because they occur at the intimate, garden level, these opportunities can add aesthetic richness that will directly benefit residents. Stormwater management techniques can also provide habitat for wildlife, create shade, improve character, provide supplemental irrigation water, and promote growth of landscape planting.

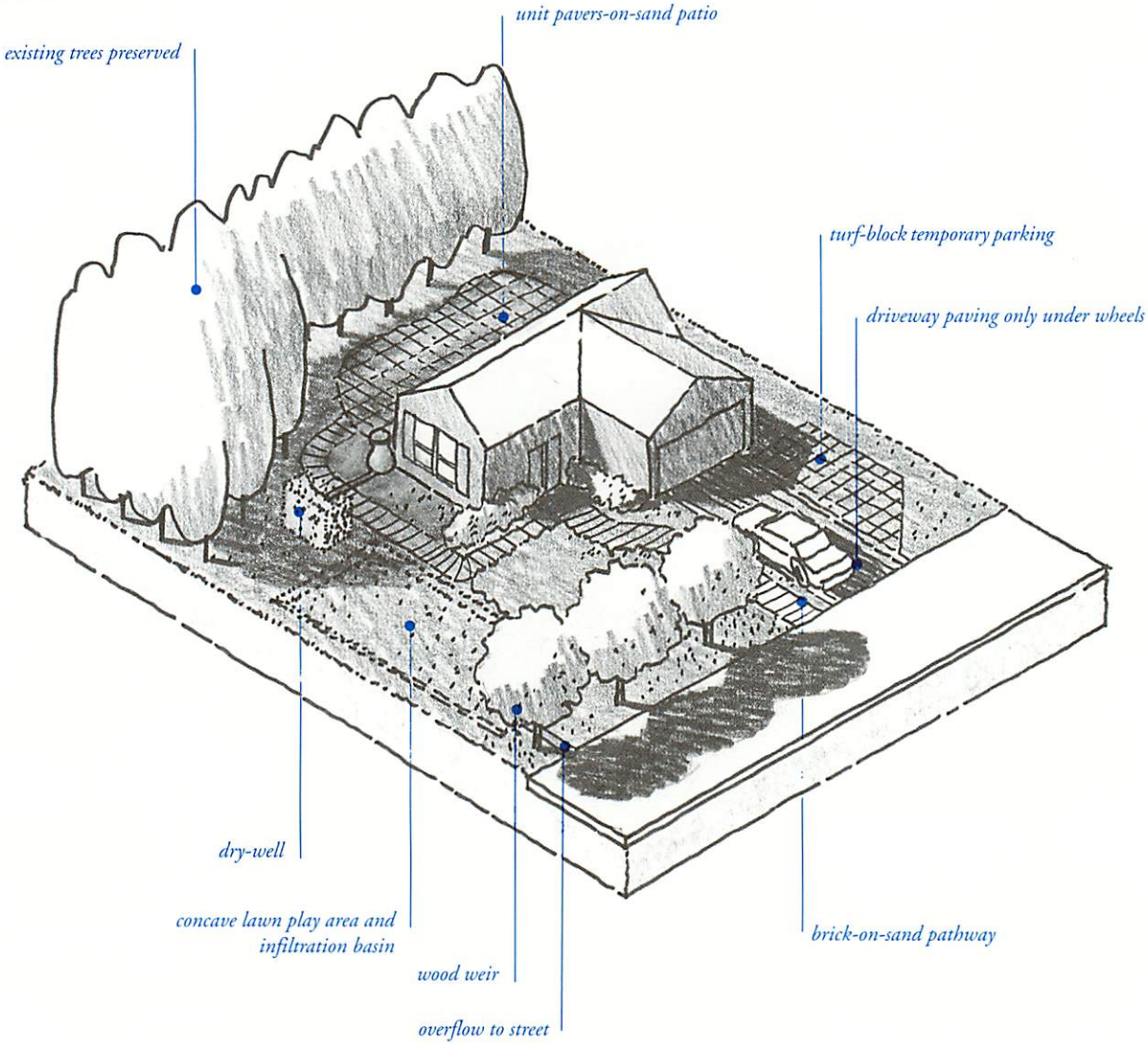
Homeowner education is an important element of stormwater management techniques at all levels, but especially at the single lot scale. Residents need to be educated on the intent of various design elements, and their proper care. They especially need to understand the maintenance needs of more active elements, such as cisterns, which need periodic cleaning or emptying. If dry-wells are included, residents must also understand that they are for rainwater only – never as a place to dump oil or other unwanted wastes.

The techniques illustrated in this example are:

- unit pavers-on-sand patio
- not directly connected impervious driveway
- unit pavers-on-sand pathway
- dry-well connected to roof downspout
- cistern
- vegetation for water retention (deep rooted trees)
- vegetation at dripline of roof.

Case Study

6.2 *Large single lot*



6.2 Large single lot. A large single-family home lot usually provides many opportunities for stormwater management. Because the ratio of impervious cover relative to land area is usually low, adequate landscape area is available to accommodate a variety of subtle infiltration strategies.

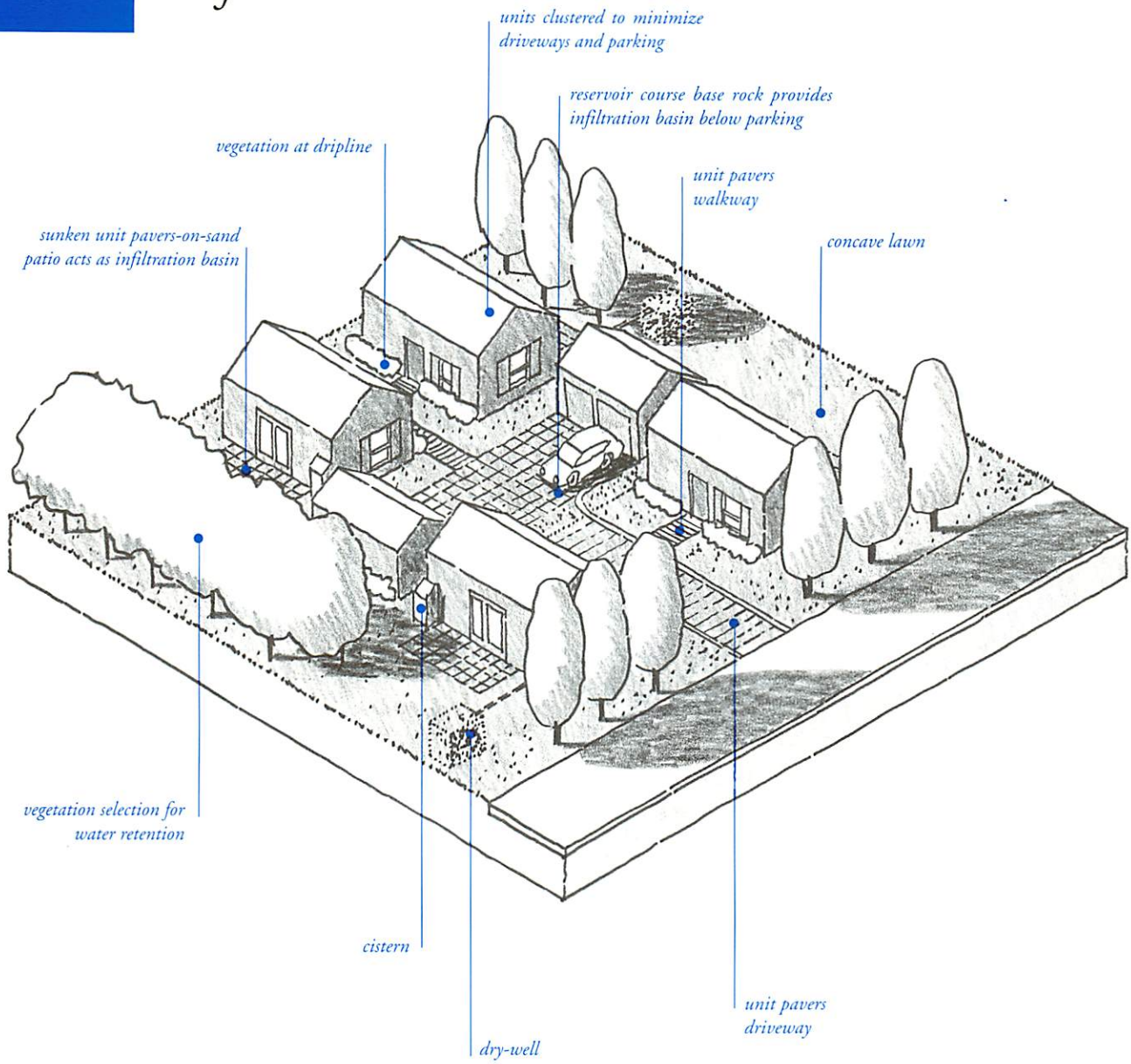
As will the small single lot, homeowner education is important so that residents understand the intent of various design elements, and their proper care. They especially need to understand the maintenance needs of more active elements, such as cisterns, which need periodic cleaning or emptying. If dry-wells are included, residents must also understand that they are for rainwater only – never as a place to dump oil or other unwanted wastes.

The techniques illustrated in this example are:

- unit pavers-on-sand patio
- concave lawn play area and infiltration basin
- not directly connected impervious driveway
- brick-on-sand pathway
- dry-well connected to roof downspout
- cistern
- vegetation for water retention (deep rooted trees)
- vegetation at dripline of roof.

Case Study

6.3 *Infill site*



6.3 Infill site. In the Bay Area, many of the sites for new construction are infill or redevelopment sites. These sites usually have higher densities (typically from 12 to 40 units per acre) which demands a greater proportion of pavement and roof coverage.

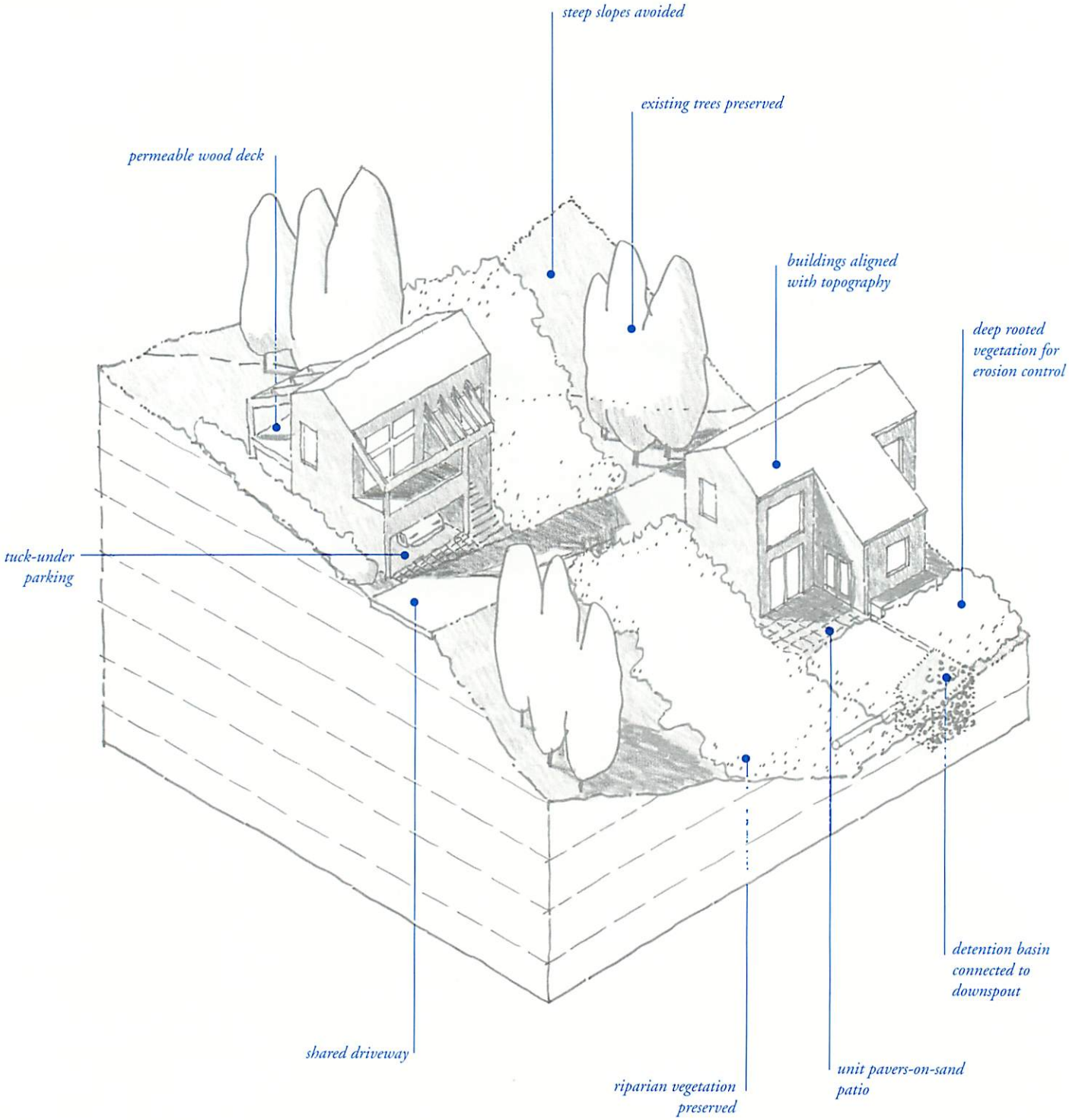
Opportunities for on-site stormwater management usually still exist, even in the most densely developed infill site, though they may require greater creativity or multiple use of space.

The techniques illustrated in this example are:

- unit pavers-on-sand patio
- concave lawn play area and infiltration basin
- not directly connected impervious driveway
- brick-on-sand pathway
- dry-well connected to roof downspout
- cistern
- vegetation for water retention (deep rooted trees)
- vegetation at dripline of roof.

Case Study

6.4 *Small hillside site*



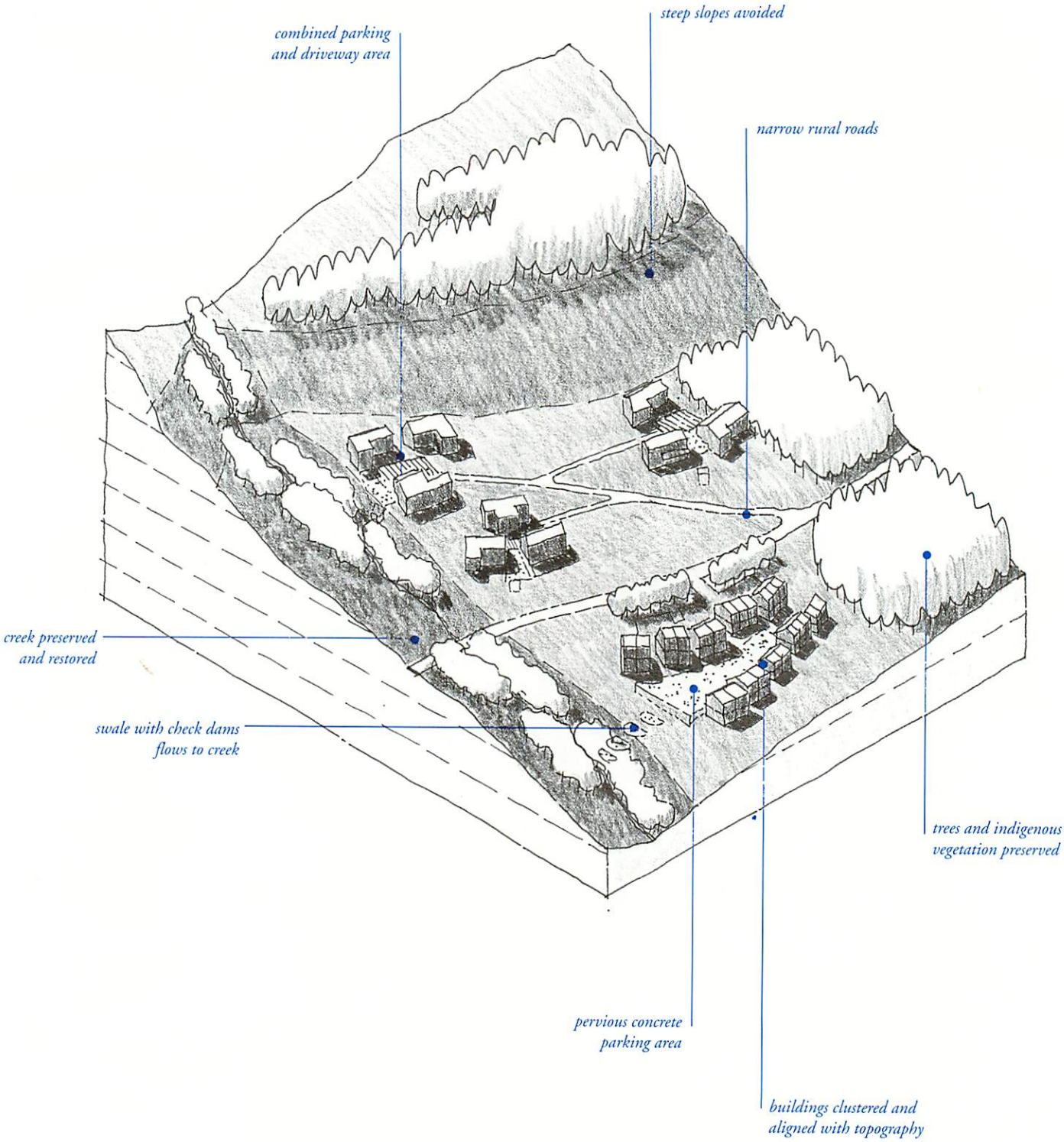
6.4 Small hillside site. Hillside sites present particular challenges for stormwater management. Because slopes are often pronounced, some infiltration strategies that are best suited to more level sites are impractical. Erosion must be prevented through siting with contours to minimize grading and careful stabilization of disturbed slopes. Finally, drainage systems, infiltration basins and detention devices must be located so that water does not compromise the integrity of building foundations and other structures.

The techniques illustrated in this example are:

- avoidance of steep slopes
- buildings aligned with topography to minimize grading
- preservation of existing trees
- preservation of riparian vegetation
- deep rooted vegetation for erosion control
- shared driveway
- tuck-under parking
- permeable wood deck for outdoor use area
- unit pavers-on-sand patio
- detention basin connected to roof downspout (downslope from building)

Case Study

6.5 *Large hillside site*



6.5 Large hillside site. Larger hillside sites present similar challenges as smaller sites, but sometimes offer more opportunities for stormwater management. Because slopes are often pronounced, some infiltration strategies that are best suited to more level sites are impractical. Erosion must be prevented through siting with contours to minimize grading and careful stabilization of disturbed slopes. Finally, drainage systems, infiltration basins and detention devices must be located so that water does not compromise the integrity of building foundations and other structures.

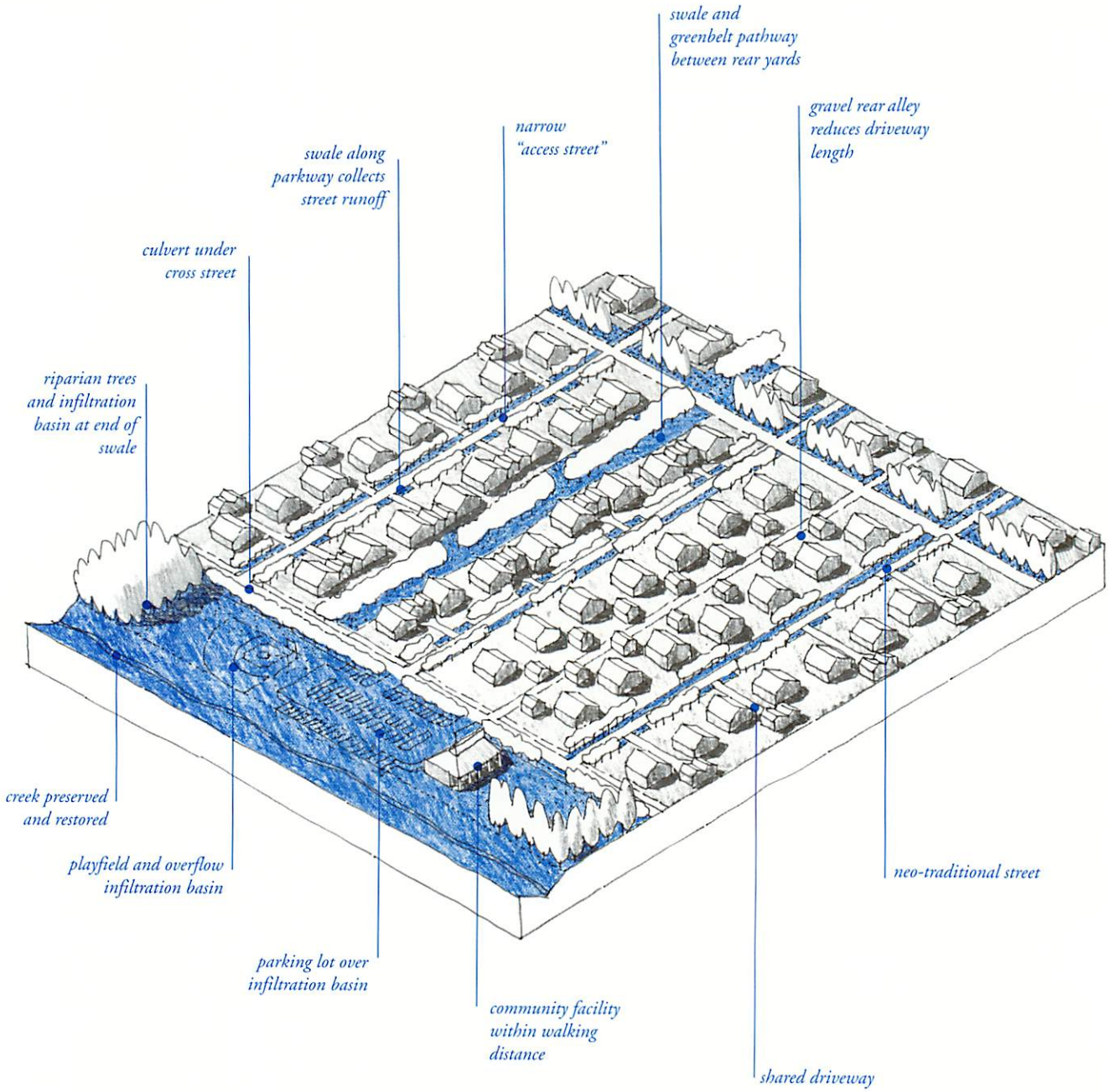
This example shows a large scale application of the site planning and design principles discussed earlier. Each cluster of buildings could also contain the finer grain elements like those illustrated for the small hillside site (6.4).

The techniques illustrated in this example are:

- avoidance of steep slopes
- buildings clustered and aligned with topography
- preservation of existing trees and indigenous vegetation
- creek preserved and restored
- narrow rural roads
- combination parking and driveway area
- pervious concrete parking area
- swale with check dams flows to creek

Case Study

6.6 *Large flat site*



6.6 Large flat site. Larger flat sites present some of the greatest opportunities for stormwater management. If soils have adequate percolation rates, infiltration swales and basins are easily incorporated. In more poorly drained soils, flat sites allow for detention and retention systems to slow the speed of runoff and hold it for later release. This allows sediments to settle and minimzes stream bank erosion from high velocity flows.

This example applies the site planning and design principles discussed earlier at the neighborhood scale. For the purposes of illustration, two different street access systems are shown: driveways from the street or rear alley access. Each has different planning implications, but both can be integrated with appropriate stormwater management.

Each cluster of buildings could also contain the finer grain elements like those illustrated for the small single lot, large single lot and infill site (6.1, 6.2, 6.3).

The techniques illustrated in this example are:

- neo-traditional street design
- gravel rear alley reduces driveway length
- shared driveways to minimze pavement
- community facility within walking distance
- parking lot over infiltration basin
- depressed playfield with multiple use as infiltration basin
- swale along parkway collects street runoff
- culvert to carry parkway swale under cross street
- riparian trees and infiltration basin at end of swale
- swale and greenbelt pathway between rear yards

7 Next Steps

This document illustrates an approach and philosophy towards residential site planning and design for stormwater management. The design details and site planning principles presented here are proven, practical methods for reducing the impact of new development on environmental quality.

This approach seeks to restore the hydrologic cycle by infiltrating runoff into the soil as close to its source as possible. It proposes simple site planning principles to cluster development, preserve natural areas, and avoid development on fragile lands. It accepts impervious land coverage as an environmental indicator, and seeks to maximize the permeability of new development. It aims to achieve all these objectives economically while creating communities that are more beautiful and desirable places to live.

The document has one goal: to create better projects. Because of the complex nature of new development, this goal can only be achieved if developers, regulatory agencies, local governments, designers, and others in the real estate industry work cooperatively.

Each group active in the new residential development can take a series of steps to create better residential projects.

Next Steps

Residential communities can be built that reward investment, are kind to the natural environment, and make better places for people to live.

Frequently asked questions

7.1 Frequently asked questions

The techniques described in this document have three basic goals:

- to minimize or reduce overall impervious land coverage,
- to ensure that remaining impervious areas are not directly connected to a storm drain system as far as feasible, and
- to slow runoff within a drainage system.

Because this approach is different than the conventional stormwater management approach of conveying water offsite as quickly as possible – "getting rid of the water" – it often raises questions. A few of the most frequently asked questions are addressed below.

If pollutants infiltrate into the soil, will there be a problem with contaminated soil or groundwater in the long term?
Not usually, especially in residential areas. The risk of contamination is a function of a compound's relative mobility, concentration, and solubility. In residential areas, the concentrations of most pollutants are generally low, and capturing them in the ground where they will eventually degrade is usually the best way to manage them. A recent study published by the U.S. EPA found that residential areas pose the lease risk of groundwater contamination from infiltration practices. This study found that the risk from compounds with greatest potential for groundwater pollution – nitrate-nitrogen, pesticides, organic compounds and heavy metals – was generally low provided that runoff percolates through the soil layer. Runoff from some sites in residential communities with higher concentrations of pollutants, such as car wash facilities and service stations, may not be suitable for infiltration.

If water is standing in pools, won't they breed mosquitoes?
Not if the pools are properly designed. All of the techniques described in this document that utilize surface drainage – such as infiltration basins, biofilters, and detention basins – can be designed to dry up within 48 hours of a storm. Even an extended retention basin, which is a semi-permanent pool that holds water for two or three weeks, will dry up in the spring before temperatures are warm enough to breed mosquitoes.

What about expansive clay soils that don't infiltrate?
The Bay Area's expansive clay soils – with their high runoff potential and low infiltration rates – present special challenges. Also, because these soils have a high swelling potential, care must be taken to prevent damage to foundations from saturated soils. Though infiltration may not be feasible, retention and detention strategies that hold water for later release are often practical. Minimizing impervious land coverage and directly-connected impervious areas are also viable strategies, even in expansive clay soils.

You recommend reducing street widths by adopting "neo-traditional" standards. How is that going to help?
The street is the single most important design element in residential site planning. Reducing street widths can reduce overall impervious land coverage significantly. For example, most Bay Area municipal street standards mandate between 80 and 100% impervious surface coverage in the right-of-way for streets, curb, gutter and sidewalk. If new standards are adopted for the most lightly traveled local streets, impervious surface coverage can be reduced by 25 to 60%. This alone helps to reduce the generation of "new" runoff from a proposed development. If the street design includes alternative stormwater collection strategies, such as linear biofilters and infiltration basins rather than standard catch basins and storm drains, the pollution generated by vehicles can be controlled near its source.

What about cost? Aren't these designs expensive to build?
These designs emphasize source control because it's the cheapest form of pollution control. Treatment control systems – collecting pollutants and treating them at the end of a pipe before the outfall – are more expensive to build and maintain, and require treating greater quantities of runoff.

Of the source control designs illustrated here, costs vary. Some designs, like concave vegetated surfaces or sloping driveways towards adjacent landscape rather than towards curbs and gutters, are cost neutral. Others, like gravel parking aisles, are less costly than conventional pavements. Cluster development, a strategy for minimizing overall impervious land coverage, can be less expensive than conventional development because of re-

ductions in roadway and utility requirements. Some of the techniques, such as pervious concrete, do add cost when compared to conventional materials, but these costs can sometimes be offset by savings generated by not having to install an underground drainage system.

Aren't these designs more expensive to maintain? And who's responsible for maintaining them, anyway?

Though some of the design details need special maintenance, many of them don't. For example, a lawn with a gently sloping concave surface requires the same maintenance as one that is convex. Yet the concave lawn holds water, making it a stormwater management device, while the convex lawn sheds water, making it a contributor to "new" runoff. Overall, the maintenance requirements of the designs recommended here can be comparable to conventional practice, though they may require a different kind of maintenance.

Maintenance responsibility will depend on the control's design and location. Some controls located on private property, such as a dry well or concave lawn near a home, will be maintained by the homeowner. Other controls, such as swales or basins along streets or in parks, may be maintained by a public agency. Still others may be the responsibility of a homeowner's association or management company. In all cases adequate maintenance and proper education are critical to the long-term viability of each control. Once people understand the design intent of a control, and are given guidance on its proper maintenance, acceptance increases and maintenance effort can be optimized.

What about liability?

Compared to building large, single detention basins, the approach described in these pages minimizes risk. By minimizing impervious surface coverage and creating multiple, small basins in the landscape, overall runoff is reduced, and the runoff that remains is held in small, shallow pools for limited periods of time. These small source controls, if properly designed and maintained, present very limited risk.

For example, Village Homes, in Davis, California was built in the mid-1970s using a surface drainage system that includes infiltration basins in private gardens, community lawns and children's playgrounds connected by a continuous network of seasonal swales and pools. For over twenty years this system has functioned successfully in a residential environment with no injuries or litigation associated with the storm drain system.

These concepts seem feasible. What is the key to their successful implementation?

There are three basic elements to successful implementation of a stormwater management system for water quality protection: correct design, proper maintenance, and public education.

The stormwater system must be integrated with the overall site plan, and each design detail must be properly designed and constructed. Once installed adequate and correct maintenance must be practiced. Finally, homeowners and maintenance staff must understand the system's intent and how to manage it.

With these elements working together, stormwater management systems can be installed and maintained that protect water quality, reduce potential for flooding, improve aesthetics and minimize costs.

This manual is fun and informative. Where can I get more copies?

Call your local stormwater program (see Resources, p. 74). They can get you more copies of this manual and help you to implement its design philosophy into your project.

Getting started

7.2 Getting Started

The following lists illustrate the wide range of options available that each of the groups active in residential development can take to begin implementing guidelines for better site planning and design. The lists are not meant to be mandates or all-inclusive, but to serve as a menu for each community to select from depending upon priorities, resources, and local conditions.

Regulatory agencies

promote education and exchange of information on stormwater management

create a regulatory environment that facilitates the implementation of better stormwater management practices

assist local governments in the monitoring and evaluation of alternative stormwater management practices

recognize and reward projects that take risks and that embrace better stormwater management practices.

Local governments

adopt standards and alternatives for design and stormwater management, such as impervious surface reduction and on-site stormwater infiltration or detention

establish an incentive program to encourage alternatives that achieve water quality goals

establish a penalty program for projects that do not achieve water quality goals

adopt access street standards for low volume, access streets

adopt drainage standards and details that permit surface drainage and infiltration/retention systems in combination with conventional underground conveyance systems

review zoning and other ordinances for driveways, setbacks, lot coverage, and other factors to accommodate more environmentally responsible land use

modify maintenance practices on public lands and in the public right-of-way to accommodate stormwater infiltration/detention systems

build a culture of environmental stewardship across all departments and offices

use these principles and techniques in siting and designing government facilities.

The building industry

think of water as an amenity to be featured rather than a liability to be gotten rid of or a hazard from which the public must be protected

market the stormwater system as a landscape feature that can improve product competitiveness

explore techniques that have proven successful elsewhere, but have not yet been widely used in the Bay Area

work cooperatively with local governments to build prototype projects that demonstrate better stormwater management practices

invest in designs and materials that may have a higher initial cost, but that yield long-term value

educate landscape crews on maintenance practices for stormwater infiltration systems and soil health

exhibit a willingness to take risks in order to advance the industry and improve the environment.

Design professionals

invest in continuing education to learn about better stormwater management practice and design

educate clients and approval bodies on the principles and advantages of designing residential developments for better stormwater management

test designs and approaches to ensure successful implementation

conceive of the drainage system as a fundamental design element to be creatively explored

complete post-construction review of built projects to evaluate long-term performance of stormwater system designs

practice continuous incremental improvement of stormwater system designs and detailing.

Resources

7.3 Resources

The following resources are available for further information and assistance with particular aspects of site planning and design for stormwater management protection.

Regional water resources and pollution prevention

Bay Area Stormwater Management Agencies Association (BASMAA)
2101 Webster Street, Suite 500
Oakland, California 94612
voice: 510 286.1255

Alameda Countywide Clean Water Program
510 670.5543

Contra Costa Clean Water Program
510 313.2360

San Mateo Countywide Stormwater Pollution Prevention Program
415 599.1406

Vallejo Sanitation and Flood Control District
707 644.8949

Fairfield-Suisun Urban Runoff Management Program
707 429.8930

Marin County Stormwater Pollution Prevention Program
415 485.3363

Santa Clara Valley Urban Runoff Pollution Prevention Program
800 794.2482

California Regional Water Quality Control Board
San Francisco Bay Region
2101 Webster Street, Suite 500
Oakland 94612
510 286.1255

Central Valley Region
3443 Routier Road, Suite A
Sacramento 95827
916 255.3000

California Environmental Protection Agency
State Water Resources Control Board
901 P Street
Sacramento, California 95814
voice: 916 657.1025
fax: 916 657.2388

Local planning and development

Association of Bay Area Governments (ABAG)
P.O. Box 2050
Oakland, California 94604-2050
voice: 510 464.7900
fax: 510 464.7970
info@abag.ca.gov

Out-of-state planning and pollution prevention

Site Planning for Urban Stream Protection
available from Department of Environmental Programs
Metropolitan Washington Council of Governments
777 N. Capitol Street, Suite 300
Washington, DC 20002
voice: 202 962.3200

The Center for Watershed Protection
8737 Colesville Road, Suite 300
Silver Spring, Maryland 20910
voice: 301 589.1890

Nonpoint Education for Municipal Officials (NEMO)
Univ. of Connecticut Cooperative Extension System
1066 Saybrook Road, Box 70
Haddam, Connecticut 06438
voice: 860 345.4511
fax: 860 345.3357
hnelson@canr1.cag.uconn.edu

Technical documents

California Storm Water Best Management Practice Handbooks
Stormwater Quality Task Force (Roesner, Walker, et. al.).
available through Blue Print Service, Oakland, CA.
510 444.6771

Design and Construction of Urban Stormwater Management Systems
American Society of Civil Engineers Manuals and Reports of Engineering Practice No. 77
Water Environment Federation Manual of Practice FD-20
jointly published by ASCE and WEF, 1992

Urban Runoff Quality Management
WEF Manual of Practice No. 23
ASCE Manual and Report on Engineering Practice No. 87
jointly published by American Society of Civil Engineers (ASCE) and the Water Environment Federation (WEF)
voice: (WEF) 703 684.2400

Stormwater Infiltration
by Bruce K. Ferguson
CRC Press
Boca Raton, FL

Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality
Environmental Protection Agency (EPA-440/5-87-001)
Washington, DC

Economic Benefits of Runoff Controls
Environmental Protection Agency. (EPA 841-S-95-002)
Washington, DC

On-site Residential Stormwater Management Alternatives
Dept. of Civil Engineering
University of Washington
3201 Fremont Avenue North
Seattle, Washington 98103
206 543.5539

Impervious Surface Reduction Study
City of Olympia Public Works Department
P.O. Box 1967
Olympia, Washington 98507-1967
voice: 360 753.8598
fax: 360 753.8087

Traffic Engineering for Neo-Traditional Neighborhood Design
Institute of Transportation Engineers (ITE)
525 School Street, S.W., Suite 410
Washington, DC 20024-2729
voice: 202 544.8050
fax: 202 863.5486
http://www.ite.org

A Appendices

The following pages provide supplementary information for those seeking more detail on residential site planning and design guidance for stormwater quality.

The appendices were adapted from a variety of technical sources drawn from throughout the United States.

Appendices

A.1 Glossary. Relevant terms and acronyms used in the text and common to stormwater management issues.

A.2 Bibliography. A listing of relevant documents on site planning and design for stormwater management. These documents address a wide range of approaches to current practice, including engineering, environmental science, landscape arcitecture, planning, horticulture, real estate marketing and development.

A.3 Footnotes. References for information cited in the text.

Appendix A.1 *Glossary*

Access streets The lowest order street in the hierarchy of streets, it conducts traffic between individual dwelling units and higher order streets (such as collector and subcollector streets). Access streets convey the lowest traffic volume, and are prime candidates for reduced street widths.

Alternative modes of transportation Modes of transportation other than the single passenger automobile, such as transit, bicycling, carpooling, and walking.

Alternative surfaces Pavement types other than conventional asphalt or concrete. Examples include porous pavement and pavers.

Amenity Something that increases material or physical comfort.

Aquifer The underground layer of rock or soil in which groundwater resides. Aquifers are replenished or recharged by surface water percolating through soil. Wells are drilled into aquifers to extract water for human use.

Arterial street A street that provides a direct route for long-distance travel within the region and also to different parts of the city. Traffic on an arterial street is given preference at intersections, and some access control may be considered in order to maintain capacity to carry high volumes of traffic.

Average daily traffic (ADT) The average total number of vehicles that traverse a road or highway on a typical day. Often used to classify and design roadway systems.

Best Management Practice A method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules & regulations developed pursuant to the federal Clean Water Act (40 CFR 1 30).

Bioretention A technique that uses parking lot islands, planting strips, or swales to collect and filter urban stormwater, that includes grass and sand filters, loamy soils, mulch, shallow ponding and native trees and shrubs.

Buffer A zone created or sustained adjacent to a shoreline, wetland or stream where development is restricted or prohibited to minimize the negative effects of land development on animals and plants and their habitats.

Building footprint Commonly used term to describe the ground area that a building covers.

Catchment The smallest watershed management unit, defined as the area of a development site to its first intersection with a stream, usually as a pipe or open channel outfall.

Check dam (a) A log or gabion structure placed perpendicular to a stream to enhance aquatic habitat. (b) An earthen or log structure, used in grass swales to reduce water velocities, promote sediment deposition, and enhance infiltration.

Cluster Development A development pattern for residential, commercial, industrial, institutional, or combination of uses, in which the uses are grouped or "clustered," through a density transfer, rather than spread evenly throughout the parcel as in conventional lot-by-lot development. A local jurisdiction's Critical Area Program may authorize such development by permitting smaller lot sizes if a specified portion of the land is kept in permanent open space to provide natural habitat or open space uses through public or private dedication.

Collector street Acts as the primary traffic route within a residential or commercial area.

Constructed wetland An artificial wetland system designed to mitigate the impacts of urban runoff.

Contamination. The impairment of water quality by waste to a degree that creates a hazard to public health through poisoning or through the spread of disease.

Cul-de-sac A circular section located at the end of an access street that permits vehicles to turn around.

Curbs A concrete barrier on the margin of a road or street that is used to direct stormwater runoff to an inlet, protect pavement edges, and protect lawns and sidewalks from encroachment by vehicles.

Density The average number of families, persons, or housing units per unit of land, usually density is expressed "per acre".

Design storm A rainfall event of specified size, intensity, and return frequency (e.g., a storm that occurs only once every 2 years) that is used to calculate runoff volume and peak discharge rate.

Detention The temporary storage of storm runoff which is used to control discharge rates sufficiently to provide gravity settling of pollutants.

Detention time The amount of time water actually is present in a basin. Theoretical detention time for a runoff event is the average time parcels of water reside in the basin over the period of release from the basin.

Drainage basin (see Watershed) A land area bounded by high points, which drains all surface water into a single stream or other body of water.

Effective Impervious Surface The portion of impervious surface that generates stormwater runoff which must be managed or directed to a stormwater conveyance system, rather than infiltrating into the ground.

Ephemeral stream A stream or waterway that holds water only for a few hours or days, and dries up shortly after rain storms.

Erosion The wearing away of land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road, building, or timber cutting.

Evapotranspiration The loss of surface water into the atmosphere, through plants and evaporation.

Excess parking Parking spaces that are constructed over and above the number required or predicted based on the parking demand ratio for a particular land use or activity

Excess stormwater runoff Any increase in stormwater resulting from: an increase in the imperviousness of a site, including all additions to buildings, roads, and parking lots; changes in permeability caused by compaction during construction or modifications in contours, including the filling or drainage of small depression areas; the alteration of drainageways, or regrading of slopes; the destruction of forest; or the installation of collection systems to intercept street flows or to replace swales or other drainageways.

Filter fabric Textile of relatively small mesh or pore size that is used to (a) allow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable).

Filter strips A vegetated area that treats sheetflow and/or interflow to remove sediment and other pollutants. Used to treat shallow concentrated stormflows over very short contributing distances in urban areas.

First flush The delivery of a disproportionately large load of pollutants during the early part of storms due to the rapid runoff of accumulated pollutants. The first flush of runoff has been defined several ways (e.g., one-half inch per impervious acre).

Forebay An extra storage space provided near an inlet of a wet pond or constructed wetland to trap incoming sediments before they accumulate in the pond.

Grassed channel A long, open, and grassed channel used to convey stormwater runoff to a downstream point. It is designed to filter out pollutants during water quality storms, and also convey large storm events.

Green space The proportion of open space in a cluster development that is retained in an undisturbed vegetative condition.

Groundwater Water stored underground that fills the spaces between soil particles or rock fractures. A zone underground with enough water to withdraw and use for drinking water or other purposes is called an aquifer.

Habitat The specific area or environment in which a particular type of plant or animal lives. An organism's habitat must provide all of the basic requirements for life and should be free of harmful contaminants.

Appendix A.1 *Glossary (continued)*

Hammerhead A "T" shaped turnaround option for lightly traveled residential streets. Creates less impervious cover compared to a circular cul-de-sac.

Headwater stream A term for the smaller first and second order tributary streams in a drainage network.

Heat island effect The increase in ambient temperatures generated by heat radiating from paved surfaces exposed to sunlight.

Hydrology The science of the behavior of water in the atmosphere (air), on the surface of the earth, and underground.

Impermeable Not able to be infiltrated by water.

Impervious surface Any surface which cannot be effectively (easily) penetrated by water. Examples include pavement, buildings, compacted soils, and rock outcrops.

Imperviousness The percentage of impervious cover within a development site or watershed.

Infill Developing vacant parcels or redeveloping existing property to achieve higher density in urban areas as an alternative to development in outlying rural areas.

Infiltration The downward entry of water into the surface of the soil, as contrasted with percolation which is movement of water through soil layers.

Interconnected streets Street system that allows traffic to circulate within neighborhoods instead of creating cul-de-sacs and dead end streets that result in disconnected residential areas. A grid pattern of blocks is a typical example.

Nonpoint source pollution Pollution that enters water from dispersed and uncontrolled sources, such as rainfall or snowmelt moving over and through the ground rather than single, identifiable sources. A nonpoint source is any source of water pollution that does not meet the legal definition of point source in section 502(14) of the Clean Water Act (e.g., forest practices, agricultural practices, on site sewage disposal, automobiles, and recreational boats). While individual sources may seem insignificant, they may contribute pathogens, suspended solids, and toxicants which result in significant cumulative effects.

Non-renewable resources Resources that are not naturally regenerated or renewed.

Nonstructural control A practice that does not require construction of a facility to control urban runoff.

NPDES National Pollutant Discharge Elimination System, a provision of the Clean Water Act that prohibits discharge of pollutants into waters of the United States unless a special permit is issued by EPA, a state, or another delegated agency.

Open space A portion of a cluster development that is set aside for public or private use and is not developed with homes. The space may be used for active or passive recreation, or may be reserved to protect or buffer natural areas (see also green space)

Perennial streams A stream channel that has running water throughout the year.

Performance criteria Technical standards that govern the development process that are based on meeting general objectives for design, rather than prescribing rigid, uniform and detailed design requirements.

Permeable A type of soil or other material that allows passage of water or other liquid.

Permeable surfaces Areas characterized by materials that allow stormwater to infiltrate the underlying soils (e.g., soil covered or vegetated areas)

Pervious A soil or material that has the specific quality of allowing the passage of water or other liquid.

Point Source Pollution A source of pollutants from a single point of conveyance, such as a pipe. For example, the discharge from a sewage treatment plant or a factory is a point source.

Pollutants A chemical or other additive that adversely alters the physical, chemical, or biological properties of the environment.

Porous pavement Asphalt or concrete paving material consisting

of a coarse mixture cemented together with sufficient interconnected voids to provide a high rate of permeability.

Premium An additional charge for real estate property with an amenity such as a water view or a view of wooded land.

Receiving waters Lakes, rivers, wetlands, and coastal waters that receive runoff.

Recharge Area A land area in which surface water infiltrates soil and reaches to the zone of saturation, such as where rainwater soaks through the earth to reach an aquifer.

Recharge Infiltration of surface water to groundwater.

Retrofit To provide or add new equipment, parts, or techniques unavailable at the time of original construction.

Riparian Area Habitat found along the bank of a natural and freshwater waterway, such as a river, stream, or creek, that provides for a high density, diversity, and productivity of plant and animal species.

Runoff Water from rain, melted snow, or agricultural or landscape irrigation that flows over the land surface.

Runoff coefficient The runoff coefficient determines the portion of rainfall that will run off the watershed. It is based on the permeability and water-holding capacity of the various surfaces in the watershed. The runoff coefficient value, expressed as *C*, can vary from close to zero to up to 1.0. A low *C* value indicates that most of the water is retained for a time on the site, as by soaking into the ground or forming puddles, whereas a high *C* value means that most of the rain runs off rapidly.

Setback A zone designated to protect sensitive areas from negative impacts associated with development.

Shared parking A parking strategy designed to reduce the total number of parking spaces needed within an area, by allowing adjacent users to share parking areas during non competing hours of operation (e.g., a shared lot for a theater and an office building).

Sheetflow A flow condition during a storm where the depth of stormwater runoff is very shallow in depth and spread uniformly over land surface. This sheet flow quickly changes into concentrated channel flow within several hundred feet.

Steep slope An area of a development site that is too steep to (a) safely build on or (b) has a high potential for severe soil erosion during construction.

Stormwater conveyance A system of gutters, pipes, or ditches used to carry stormwater from surrounding land areas to constructed or natural drainage systems.

Stormwater runoff Rain that flows off the surface of the land without entering the soil.

Structural control A practice that involves design and construction of a facility to mitigate the adverse impact of urban runoff, and often requires maintenance.

Subdivision The process (and the result) of dividing a parcel of raw land into smaller buildable sites, streets, open spaces, and public areas, and the designation of utilities and other improvements. Critical Area regulations govern the density and design of new subdivisions.

Subwatershed A watershed management unit whose boundaries are typically defined as all of the land draining to the point where two second order streams combine together to form a third order stream. A subwatershed may be a few square miles in area, and are the key geographic unit for urban stream classification and watershed- based zoning,

Surface water Water on the surface of the land that has not infiltrated the soil including streams, lakes, rivers, and ponds.

Swale An open drainage channel that has been explicitly designed to detain or infiltrate the entire runoff volume associated with a water quality storm event.

Trip generation rate A statistic that indicates the number of vehicular trips that are taken from an average dwelling unit in a particular land use category on a typical day. For example, studies have shown that one single family home generates about 10 trips per day.

Unbuildable lands The portions of a development site where structures cannot be located for physical or environmental reasons (e.g., easements, open water, steep slopes, floodplains, wetlands and stream buffers).

Unit Pavers Concrete grid and modular pavement whose spaces are filled with pervious materials such as sod, sand, or gravel.

Water table The upper surface of groundwater or the level below which the soil is saturated with water. The water table indicates the uppermost extent of ground water.

Watershed (see Drainage basin) The geographic region within which water drains into a particular river, stream or body of water. A watershed includes hill, lowlands, and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds.

Wet pond Pond for urban runoff management that is designed to detain urban runoff and always contains water.

Zoning A set of regulations and requirements which govern the use, placement, spacing, and size of land and buildings within a specific area (zone).

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[1] Environmental Protection Agency, *Natural Wetlands and Urban Stormwater: Potential Impacts and Management,* EPA document 843-R-001, Feb. 1993, p. 76

[2] U.S. EPA National Water Quality Inventory, Report to Congress, 1994.

[3] Federal Register Vol. 55, No. 222, 47990-48091, Nov. 16, 1990.

[4] this discussion is adapted from: Arnold, Jr., Chester L. and C. James Gibbons, "Impervious surface coverage: the emergence of a key environmental indicator," *APA Journal,* 62,2: 243-257, and Schueler, Tom, *Environmental Land Planning Series: Site planning for urban stream protection (1995),* 19-20.

[5] Environmental Protection Agency, Natural Wetlands and Urban Stormwater: Potential Impacts and Management, p. 76.

[6] based on 40-year rainfall data from National Oceanic and Atmospheric Administration (NOAA), calculations by Prof. Bruce Ferguson.

[7] City of Olympia, 1994, p. 30. In one of the few studies that actually measured impervious surface coverage, the City of Olympia (WA) found that the street and circulation network accounted for an average of 63 to 70% of total impervious coverage in a selection of eight single family and multifamily residential developments. Also see Schueler, Tom (1995), p. 19.

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[23] Ramsey & Sleeper, *Architectural Graphic Standards,* p. 105.

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[25] personal measurements by Tom Richman, 1996

[26] Schueler, p. 148.

[27] this discussion of traffic volumes and costs related to access streets is adapted from Schueler, p. 148.

Recent household survey data indicates that the 10 vehicle per day per household rule-of-thumb overestimates actual vehicle trips, especially in neo-traditional neighborhoods where multiple modes of transportation are supported. This suggests that two-way "access streets" with shared central moving space may safely serve more than 50 residential units. Frank Spielberg, ITE Technical Review Committee, personal communication, 1996.

[28] ibid. The term "headwater streets" has been popularized by Tom Schueler of the Center for Watershed Protection.

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[30] ibid.

[31] Schueler, p. 148.

[32] Spielberg, Frank ITE Technical Review Committee, personal communication

[33] Ferguson (1994), p. 18.

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[35] Harris, p. 48

[36] Harris, p. 621

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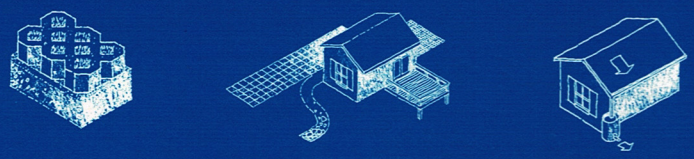
Finding that the way we design and build communities has a direct effect on water quality, the Bay Area Stormwater Management Agencies Association (BASMAA) has prepared **Start at the Source** *with a focus on residential development, including new development, infill development and redevelopment. The design guidance manual aims to help designers, developers, and municipal agencies create residential communities that achieve water quality goals. It recognizes that the one of the best opportunities to reduce the generation of "non-point source pollution" from development is through planning and design.*



"The more we study stormwater runoff, the more we realize the critical role site planning and design play in our ability to reduce the impacts of development on the quality of our nation's waters. This manual is a significant step in teaching planners and developers to plan for water quality."

Thomas E. Mumley
California Regional Water Quality Control Board
San Francisco Bay Region
Urban Runoff Program Manager

"BASMAA's *Start at the Source* guidance manual is a pioneering effort which focuses on the importance of considering storm water quality in the early stages of planning new residential development in the San Francisco Bay area."

Community Planning & Environmental Committee
Consulting Engineers and Land Surveyors of California (CELSOC)

"Through its integrative approach and illustrative method, *Start at the Source* shows how new development can be designed and built to meet functional and market demands while protecting water resources."

Jim Dalton, Executive Vice President
American Society of Landscape Architects