

8 Technical Section

The site design and landscape details illustrated here have two purposes:

- *to minimize the creation of new runoff, and,*
- *to infiltrate or detain runoff in the landscape.*

The techniques presented here illustrate an approach to design and construction for maximizing infiltration, providing retention, slowing runoff, and minimizing impervious land coverage. They are not all-inclusive, and may not be appropriate for every site or condition. Each detail is given in a generic or typical form— particular site and soil conditions must be assessed by a qualified professional to determine which details are appropriate and what modifications are required for their proper application.

Technical Section

8.1 Permeable pavements

8.2 Streets

8.3 Parking lots

8.4 Driveways

8.5 Buildings

8.6 Landscape

8.1 Permeable Pavements

Permeable pavements are a method of reducing impervious land coverage 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 soil. By making pavements permeable, impervious surface coverage can be reduced without sacrificing intensity of use.

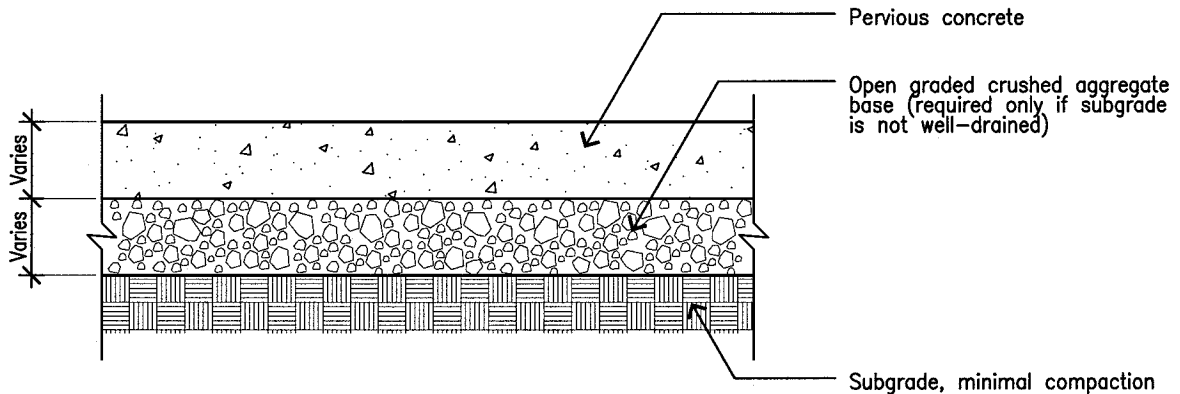
There are three main categories of permeable pavements: poured-in-place, unit pavers-on-sand, and granular materials. A typical component of these permeable pavements is a reservoir base course. This base course provides a stable load-bearing surface as well as an underground reservoir for water storage. The base course must meet two requirements:

- it must be open graded, meaning that the particles are of a limited size range, with no fines, 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.
- it must be crushed stone, not rounded river gravel. Rounded river gravel will tend to rotate under pressure, causing the surface structure to deform. The angular sides of the crushed stone will form an interlocking matrix, keeping the surface stable.

Permeable pavements must be laid on a relatively flat slope, generally 5% or flatter. If permeable pavements are laid on steep slopes, the underlying base course tends to migrate downhill, causing the surface to deform.

Permeable Pavements

Pervious concrete
Porous asphalt
Turf block
Brick
Natural stone
Unit pavers on sand
Crushed aggregate (gravel)
Cobbles



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Pervious Concrete is a discontinuous mixture of coarse aggregate, hydraulic cement, and other cementitious materials, admixtures, and water, which has a surface-void content of 15-25%, allowing water and air to pass through the pavement.

Characteristics

- Rigid, poured-in-place slab.
- Appearance similar to exposed aggregate.
- Curb and gutter system may not be necessary to control low flow.
- Runoff coefficient: very low to nil (can infiltrate up to 140 cm/h [56"/h]).
- Reduces impervious land coverage.

Applications

- Flat sites (slope $\leq 5\%$) with uniform, permeable subgrade (or appropriate depth to construct deep base).
- Low traffic volume bikeways, streets, travel lanes, parking stalls, residential driveways, patios.

- Not appropriate for gas stations, truck stops, areas in which high concentrations of hydrocarbons can be leached into the soil.

Design

- Subgrade and base rock design must be determined by a qualified professional according to soil conditions and intended use or anticipated loads.
- Subgrade must be uniform, well-drained (infiltration rate $\geq 5"/hr$). Top 6" of subgrade should be granular/gravelly soil, predominantly sandy, with low to moderate amount of clay or silt.
- Base of open graded, crushed (not rounded) stone, no fines. Must be designed to support surface uses, allow water to flow through, and prevent migration of subbase soils.
- Special attention and tools required for installation.

Maintenance

- Inspect for clogging after installation and annually; remove spot clogs.
- Some installers recommend quarterly vacuum sweeping or high pressure hosing.
- Maintenance can be high first few years, until site is fully stabilized.

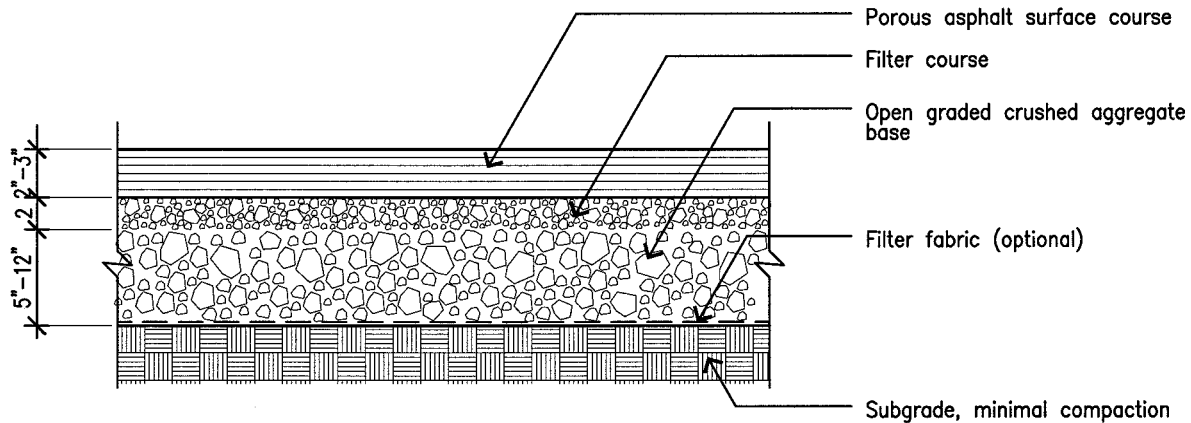
Economics

- Installation costs up to 50% greater than conventional concrete.
- Costs can be offset by savings in not installing curb and gutter drainage system.
- Maintenance cost up to 1-2% of construction cost annually.

Examples/resources

- Drain cover at Stanford Shopping Center, Palo Alto, CA.
- Tree grates in city sidewalks, Los Angeles, CA.
- Florida Concrete and Products Association (407) 423-8279.

Porous asphalt



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Porous Asphalt is an open graded asphalt concrete over an open graded aggregate base and a draining soil. It is composed almost entirely of stone aggregate and an asphalt binder. Porous asphalt is widely used as a top lift on state highways to minimize water ponding and hydroplaning. In this case it does not create a permeable pavement, because the porous (“open graded”) asphalt is laid over a conventional asphalt lift.

Characteristics

- Flexible, poured-in-place slab.
- Appearance similar to conventional asphalt, though rougher surface.
- Rough, coarse surface improves traction in wet conditions, but may result in a rough ride.

- Curb and gutter system may not be necessary to control low flow.
- Runoff coefficient: very low to nil (can infiltrate 50-150 cm/h [20-60”/h])
- Reduces impervious land coverage.

Applications

- For use in areas with low traffic use, such as parking lots, travel lanes, parking stalls (surface may be too rough for bicycle path).
- Flat sites (slope ≤ 5%) with uniform, permeable subgrade (or appropriate depth to construct deep base).
- Not appropriate for gas stations, truck stops, areas in which hydrocarbons can be leached into the soil.

- May not be appropriate in areas where children are at play (pavement may cause abrasion injuries).

Design

Asphalt mix void content of 12 - 20%.

Surface composition 4.5 - 6.5% asphalt aggregate, 2.5 - 3.0% asphaltic cement.

Base composition 5” to 12” depth open graded crushed (not rounded) 1/2 - 1” stone, having infiltration rate ≥ 5” per hour.

- Filter fabric may be required below base course.

Subgrade and base rock design must be determined by a qualified professional according to soil conditions and intended use or anticipated loads.

- Special tools required for installation.

Maintenance

- Most failures occur when substantial quantities of sediment erode onto pavement surface. This can happen if pavement is located downhill from an erosive and sediment is allowed to wash over the surface, or during construction due to a lack of erosion/sediment control measures. Void spaces then become clogged, either requiring wet-vacuuming or reducing the permeability of the surface.
- Some installers recommend quarterly vacuum sweeping and high pressure hosing, though installations are known that have had no special maintenance and remain permeable for 20 years.

- Inspect for clogging after installation and annually; remove spot clogs.
- Take measures to ensure that future property managers do not use top-coat or slurry seal, as this will clog the asphalt pores.

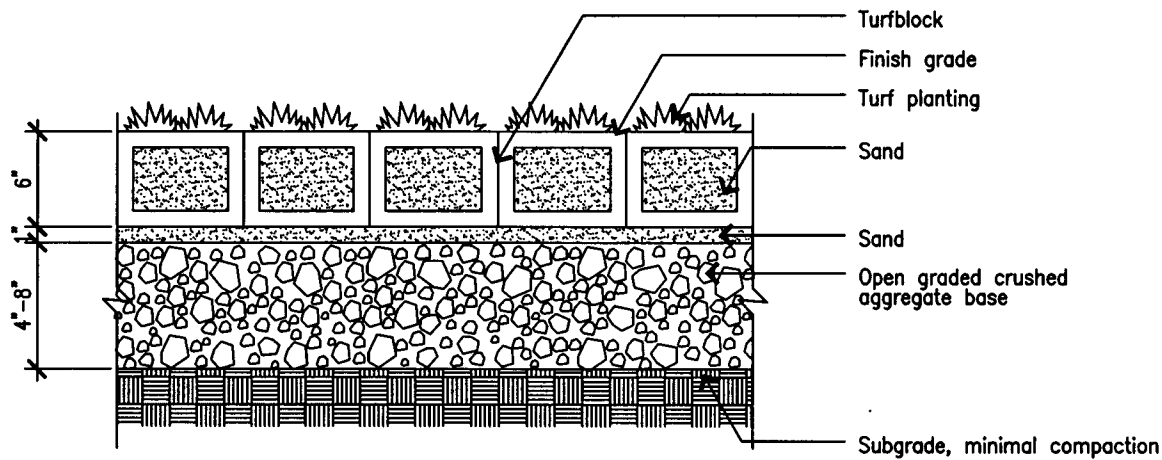
Economics

- Up to 50% more than conventional asphalt pavement.
- Costs can be offset by savings in reducing or eliminating curb and gutter drainage system.
- Maintenance cost up to 1-2% of construction cost annually.

Examples/resources

- Asphalt Institute (805) 373-5130.
- Metropolitan Transportation Commission, pavement management div. (510) 464-7700.
- CalTrans Specifications, Section 39, Asphalt Concrete “Open Graded” type.

Turf block



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Turf block is an open-celled unit paver in which the cells are filled with soil and planted with turf. Sometimes the cells are filled with crushed rock only.

Characteristics

- Units vary in size, weight, surface characteristics, strength, durability, proportion of open area, interlocking capability, runoff characteristics, and cost.
- Original turf block was made solely of concrete, newer plastic styles are available. Concrete block is bulkier, with smaller openings for soil and infiltration. The concrete draws the moisture out of the soil, tending to dry out the grass in hot, dry weather. Plastic open-celled pavers eliminate this problem and have a greater void/soil space.
- Requires deep rooted grass species that can penetrate reservoir base course. Frequent watering may be required because the bulk of root and soil mass are located in the top 3"-4".
- Curbs and gutters generally not necessary to control low flow.

- Runoff coefficient: similar to grass, 0.15-0.60.
- Permeability is directly related to the permeability of the subgrade.
- Reduces impervious land coverage.

Applications

- Areas of low flow traffic and infrequent parking such as: residential driveways, overflow parking areas, the outer 1/3 of commercial and retail developments where parking space is used less often and for shorter periods of time, fire/emergency access roads, utility roads, street shoulders.
- Not suitable for all day parking, heavy use or areas with turning movements because the grass gets insufficient sun for optimal growth, or is suppressed by constant abrasion.
- Swales in urban areas. Turf block prevents mowers from getting stuck or creating grooves in the swale.

Design

- Flat sites (slope \leq 5%)

- Base course: open-graded and composed of crushed rock (not rounded).
- Subgrade must be designed for anticipated loads.
- Provide underdrain system where there are no deep permeable soils.

- Irrigation required to maintain turf.

Maintenance

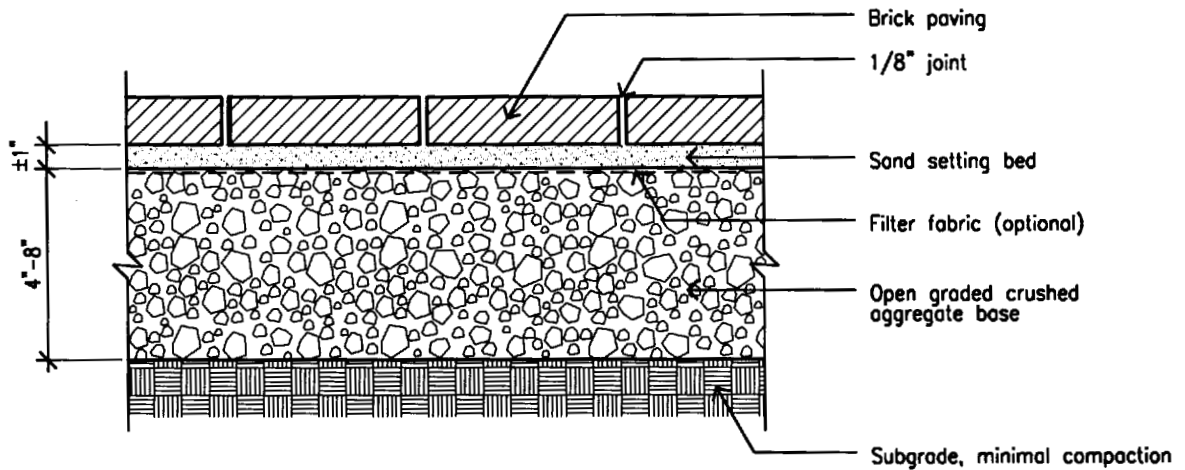
- May need occasional reseeding.
- Similar to maintenance of regular lawn, requiring mowing, fertilization, and irrigation.

Economics

- \$4-6 per square foot, installed.

Examples/resources

- Emergency access/fire lane. Guadalupe River Project, San José, CA.
- Parking lot with asphalt aisles, turf block stalls, University of Miami Orange Bowl Stadium, Miami, FL.
- Shopping mall expansion overflow parking, NEMO Project, CT.



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Brick is a solid unit paver available in a variety of colors and sizes, and a traditional building material with a long history. Bricks are typically laid either with sand joints on a crushed rock base, or with mortared joints on a concrete base. Only sand joints on a crushed rock base form a permeable pavement.

Characteristics

- Available in a variety of materials and finishes. Typically, bricks are rectangular in shape and made of a fired clay. Concrete bricks are also commonly available.
- Runoff coefficient: 0.13 to 0.76, depending on rainfall intensity and joint spacing. Brick pavement is more permeable in light rains and with wider joints.

Applications

- Driveways, walkways, patios, public sidewalks, plazas, low volume streets.
- Flat sites (slope $\leq 5\%$).
- Reduces impervious land coverage.

Design

- Because the bricks are laid loose, the field must be enclosed by a rigid frame. Concrete, mortared brick on a concrete grade beam, redwood header, and metal edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- In areas with pedestrian traffic, make joints not larger than 1/4".
- Subgrade must be designed for anticipated loads.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

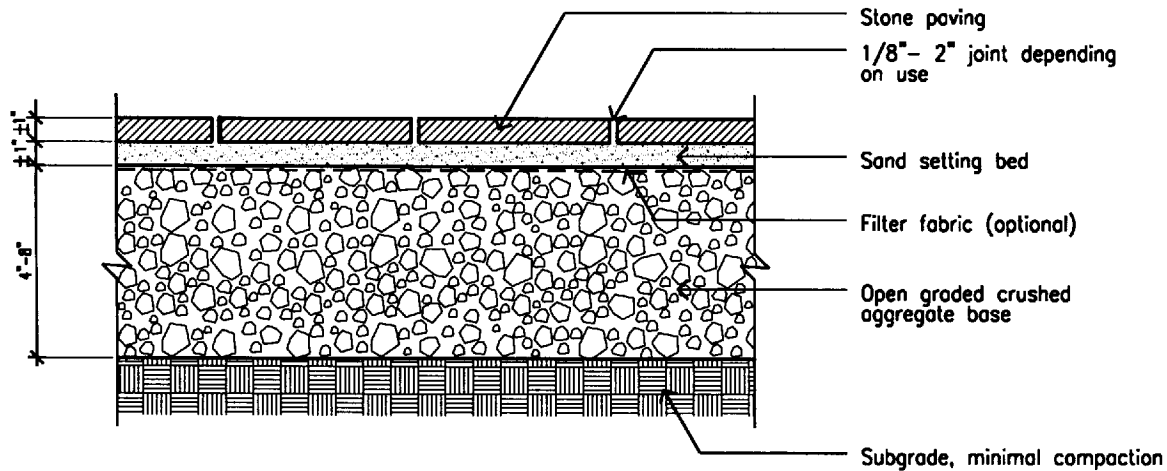
Economics

- \$6–10 per square foot. Generally more expensive than concrete or asphalt, less expensive than brick on concrete.

Examples/resources

- Widely used as patios, plazas, sidewalks, driveways.

Natural stone



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Natural stone paving is made of discrete units set in a pattern on a prepared base. A traditional building material with a long history, natural stone is typically laid either with sand joints on a crushed rock base, or with mortared joints on a concrete base. Only sand joints on a crushed rock base form a permeable pavement.

Characteristics

- Available in a variety of natural materials of varying colors, textures, shapes, and finishes. These include flagstone, slate, granite, and bluestone. For sand-set permeable pavement, the stone must be at least 1" thick— thinner pieces suitable for mortar-setting will crack if sand-set.
- Shapes range from random broken pieces of irregular patterns to cut stone of geometric patterns.
- Permeability is determined by the size of the joints. Large joints in patio or light traffic areas can be filled with plant material such as moss or turf.

- Runoff coefficient: 0.25 - 0.8 depending on joint size. Natural stone pavement is more permeable in light rains and with wider joints.

- Reduces impervious land coverage.

Applications

- Driveways, walkways, patios, low-use parking stalls.
- Flat sites (slope $\leq 5\%$).

Design

- Because the stone is laid loose, the field must be enclosed by a rigid frame. Concrete, mortared stone on a concrete grade beam, redwood header, and metal edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- Subgrade must be designed for anticipated loads.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

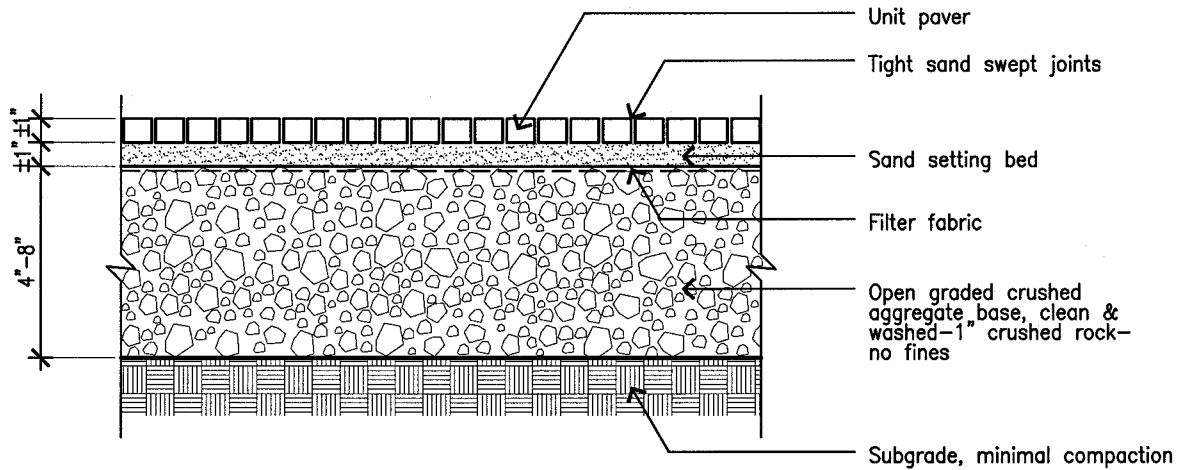
Economics

- Unit cost varies from \$10–25 per square foot, depending on material selected.

Examples/resources

- Parking lot stalls, La Casitas del Arroyo community building, Pasadena, CA.
- Widely used as patios, plazas, sidewalks, driveways.

Unit pavers on sand



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Unit pavers on sand are discrete units that are set in a pattern on a prepared base. A variation on traditional brick technology, unit pavers are typically made of pre-cast concrete in shapes that form interlocking patterns. Some of these shapes form patterns that include an open cell to increase permeability.

Characteristics

- Widely used as patios, plazas, sidewalks, driveways.
- Open celled unit pavers are designed with precast voids to allow water to pass through.
- Solid unit pavers can form a permeable surface when spaced to expose permeable joints and set on a permeable base.
- Available in a variety of materials, colors and shapes.
- Runoff coefficient: 0.1 - 0.35 (more permeable with open cells or larger joints).
- Reduces impervious land coverage.

Applications

- Parking stalls, private driveways, walkways, patios.
- Can be used for low volume streets, travel lanes, bikeways.
- Flat sites (slopes $\leq 5\%$).

Design

- Because the unit pavers are laid loose, the field must be enclosed by a rigid frame. Concrete bands, metal or plastic edgings are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- May not be suitable on expansive soils without special subgrade preparation.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.

- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

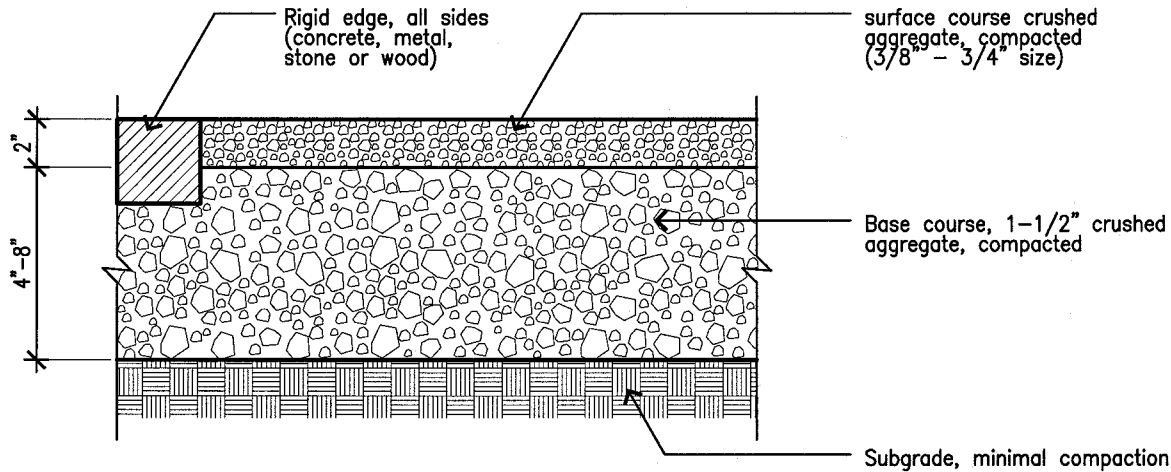
Economics

- Installation cost \$9-15 per square foot
- More expensive than conventional concrete or asphalt, less expensive than unit pavers on slab.

Examples/resources

- Ecostone, SF RIMA are two manufacturers of open-celled concrete unit pavers.
- St. Andrews Church, Sonoma CA. uses Ecostone in drop-off area near entrance.
- 3170 Porter Drive, Palo Alto, uses Ecostone in parking lot stalls to increase permeability near heritage oak trees.

Crushed aggregate



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Crushed aggregate is crushed stone ranging from sand-sized “fines” to 2” diameter stone.

Characteristics

- A granular material, crushed aggregate can be laid in any shape field or configuration.
- Runoff coefficient 0.10 – 0.40. Pavements of fine crushed stone (e.g. decomposed granite fines) is relatively impermeable. Permeability increases with larger aggregate sizes. Open graded mixes are more permeable than mixes that include fines.
- Easy to install.
- Reduces impervious land coverage.

Applications

- Low volume, low speed vehicle traffic areas.
- Parking stalls, private driveways, walkways, patios.

- Areas of low erosion.
- Not appropriate for ADA-compliant accessible paths of travel.

Design

- Because the aggregate is laid loose, the field must be enclosed by a rigid frame in most applications. Concrete, mortared brick on a concrete grade beam, redwood header, and metal edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- In areas with pedestrian traffic, use smaller aggregate (3/8” size). Larger aggregate (3/4” size) makes a better driving surface.

Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.

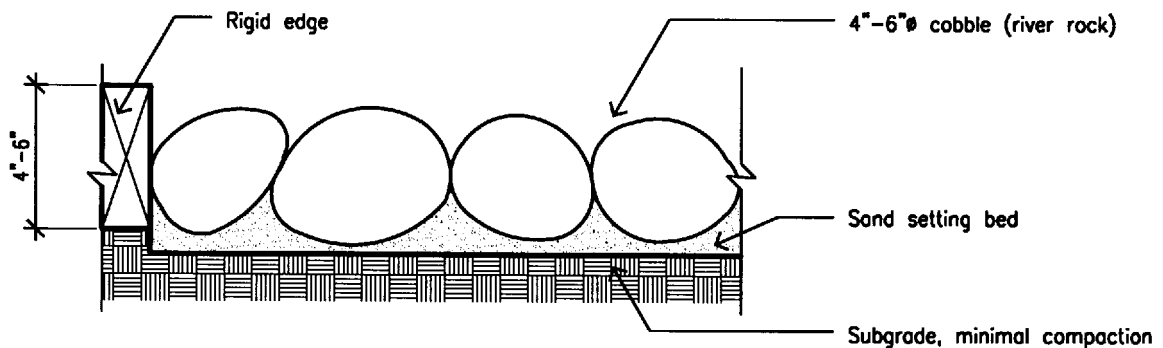
- Easy to repair, since aggregate is easily regraded and replenished.
- Occasional weed suppression may be required.
- To maximize permeability, minimize compaction of subgrade.
- Periodic and/or replenishing, raking of displaced gravel may be required.

Economics

- Less expensive than conventional asphalt or concrete pavement.
- Least expensive of all pavements, ranging from \$1 to \$3 per square foot.
- Reduced impervious land coverage reduces or eliminates need for catch basins/underground storm drain system.

Examples/resources

- Widely used as patios, plazas, driveways.



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Cobbles are natural stones of various sizes. River rock is rounded, other cobbles can be angular in shape. Cobbles are typically set in native soil with soil joints or on a mortar bed with mortared joints. Only soil set cobbles are a permeable pavement.

Characteristics

- Can be laid in a fields of any shape or configuration, with or without base.
- Material varies in color, shape, and size.
- Runoff coefficient 0.60 – 0.90; higher for larger sizes.
- Easy to install.
- Reduces impervious land coverage.

Applications

- Garden areas.
- Not suitable for walkway surface.

Design

- Rigid edge such as concrete, brick, wood or metal band is useful to keep cobbles in place.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- Diameters range from 4" to 8".
- A permeable filter fabric may be provided under the cobbles to suppress weeds and minimize migration of soil.

Maintenance

- Periodic weed suppression may be required.
- Resetting or replacement of cobbles may be required periodically.

Economics

- Easy to remove/reinstall
- Cost varies widely depending on material. Washed river rock is less costly than angular granite cobbles.

Examples/resources

- Commonly used around bases of trees in lawn areas.
- Commonly used in parkway planter strips and median islands.
- Commonly used as decorative mulch in landscaped areas.

8.2 Streets

More than any other single element, street design has a powerful impact on stormwater quality. 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.

From a technical point of view, streets present many complex design challenges. First, their design must respond to a variety of traffic loads, ranging from the most heavily travelled highway to the least travelled access street or lane. Second, street design is often mandated by a wide array of industry and government standards, many of which may conflict with current stormwater management practice.

The intent of the technical details that follow is two-fold:

- *to reduce the impervious surface area by “right-sizing” streets to fit the transportation demand, and*
- *to disconnect the street as far as possible from the underground stormwater system by incorporating infiltration/detention areas and swales into their design.*

Streets

Access street: urban neo-traditional standard

Access street: rural standard

Urban curb/swale system

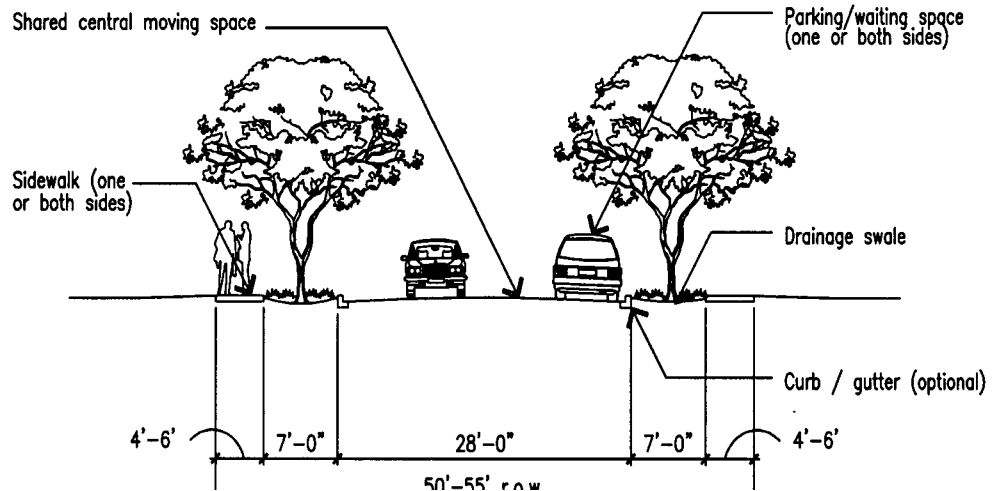
Rural swale system

Dual drainage system

Concave median

Cul-de-sac

Access street: urban neo-traditional standard



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Urban neo-traditional standard access streets have a typical pavement width of 20 to 30' for vehicular movement and parking, as compared to conventional local streets, that typically require 36 to 40' of pavement.

Characteristics

- Central shared space for traffic in both directions.
- Sidewalks provided on one or both sides of the street depending on adjacent land uses, pedestrian needs.
- Parkway on one or both sides can be used for planting and surface drainage.
- Generally utilize curbs and gutters, though the gutter may be tied to a bio-filter or swale rather than an underground storm drain.
- Reduces impervious land coverage by up to 50 percent.

- Reduces sediment, oil and grease, hydrocarbons when combined with biofilters and swales.

Applications

- Appropriate for areas where traffic volumes are at or below 500-750 ADT and speeds between 15 to 25 mph.
- Most appropriate for grid street systems.
- May not be appropriate for long cul-de-sac streets or hillside sites with high fire risks (because of the potential of shared moving space to be blocked by a single vehicle, with no alternate emergency route).

Design

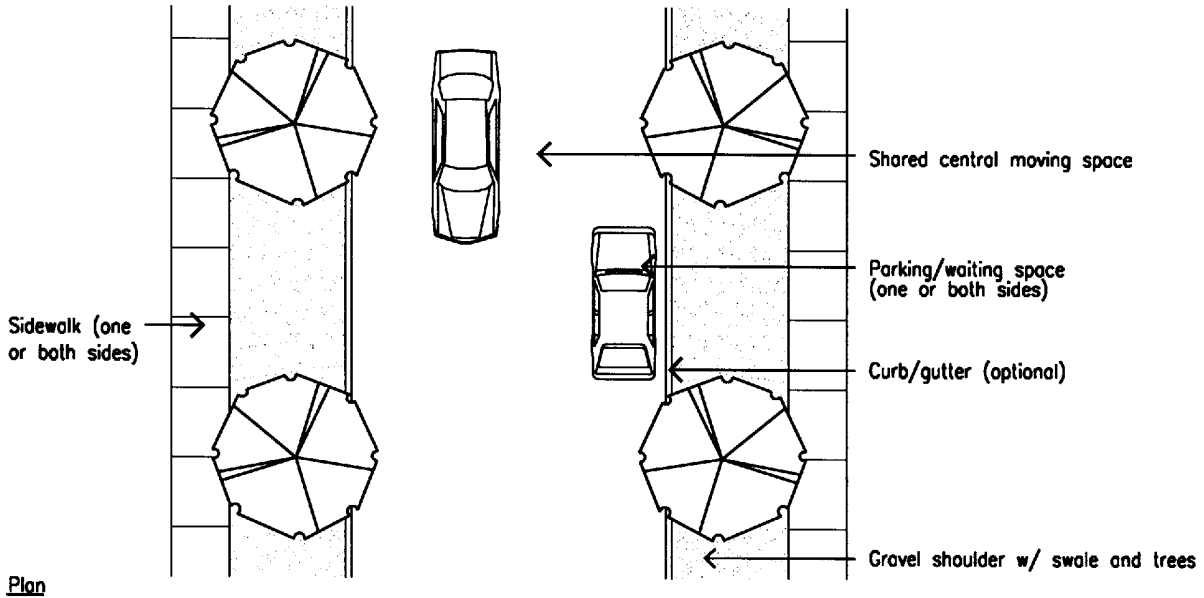
- Construction detailing same as typical street standard.
- Coordinate with local and regional zoning ordinances and public works standards.

- Streets with special uses, such as bike routes, may require additional pavement width.
- Depending on topography, parkway strip can be designed as a linear swale/biofilter, with curb openings directly into swale (see 6.2c Urban curb/swale system).

Maintenance

- Standard street maintenance practices required.
- Parkway strip between curb and sidewalk requires mowing, tree care. This can be the responsibility of the local jurisdiction or the adjacent property owner, depending on local codes and ordinances.

Access street: urban neo-traditional standard, continued



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

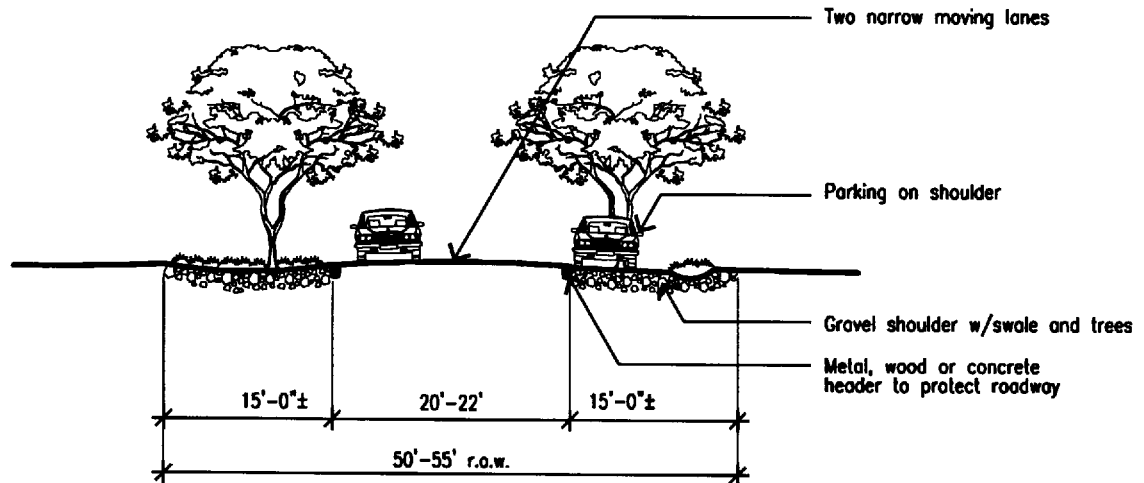
Economics

- Narrower street section reduces initial construction costs.
- Increased parkway adds additional landscape maintenance cost, especially compared with conventional street section without a parkway strip.
- Properties on narrower streets with tree-lined landscaped parkways typically command higher values than those on wider treeless streets.

Examples/resources

- Institute of Transportation Engineers (ITE) “Traditional Neighborhood Development Street Design Guidelines,” 1997.
- Skinny Streets program, Portland, OR.
- Velarde, Loreto Streets, Mountain View, CA.
- Typical of neighborhoods built before WWII.

Access street: rural standard



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Rural standard access streets have an 18'–22' two-lane paved roadway, with no curb or gutters. Gravel or crushed aggregate shoulders act as drainageway and parking area.

Characteristics

- Vehicles tend use the center of the narrow paved roadway. When two cars are present moving in opposite directions, drivers reduce speeds and move towards the right hand shoulder.
- Permeability: Road is crowned to the gravel shoulders on each side. Reduced pavement width allows for shoulder on one or both sides that can be used for planting and surface drainage.
- Reduces impervious land coverage.
- Reduces sediment, oil and grease, hydrocarbons when combined with biofilters and swales.

Applications

- Appropriate for areas where traffic volumes are at or below 500-750 ADT and speeds between 15 to 25 mph.
- May not be appropriate for long cul-de-sac streets or hillside sites with high fire risks (because of the potential of shared moving space to be blocked by a single vehicle, with no alternate emergency route).
- Rural standard presents a more informal aesthetic and is suitable for less urban locations.

Design

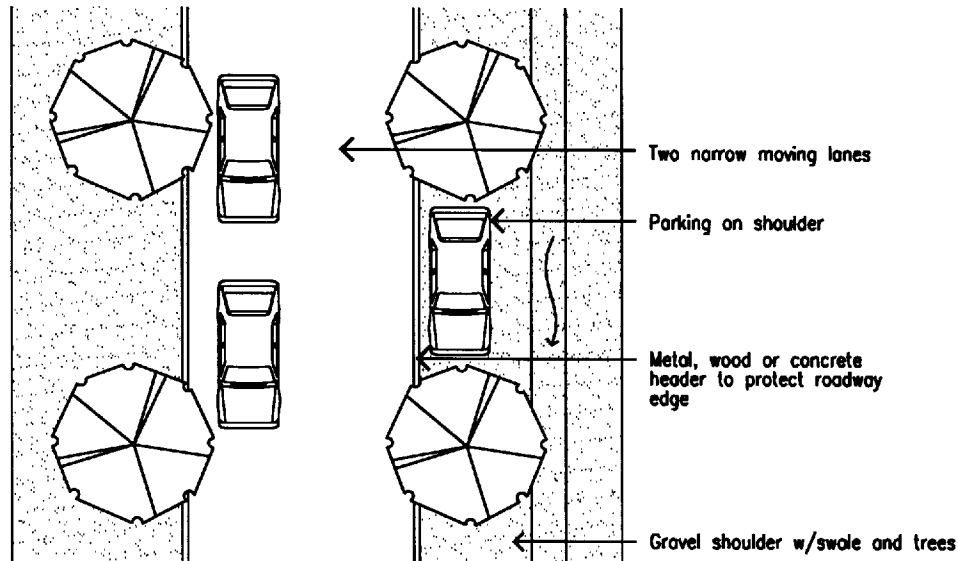
- Roadway edge protection can be achieved by flush concrete bands, steel edge, or wood headers.
- Depending on topography, gravel shoulder can be designed as a linear swale/biofilter, with water sheet flowing directly into swale.

- Parking can be organized by bollards, trees, or allowed to be informal.
- Parking can be allowed only on one side to preserve a wider moving space for emergency vehicles.
- On very low volume, low speed, access streets, sidewalks may not be required, as pedestrians walk in the street or on the shoulder.
- If catch basins are used, provide settlement basin before inlet, or raise inlet above bottom of swale, to prevent sediment from filling catch basin.

Maintenance

- Gravel shoulders require periodic regrading and replenishing.
- Elimination of curb means that conventional street sweeper machinery cannot be used.

Access street: rural standard, continued



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

- Landscaped shoulder with surface stormdrain elements requires maintenance. This can be the responsibility of the local jurisdiction or the adjacent property owner, depending on local codes and ordinances.

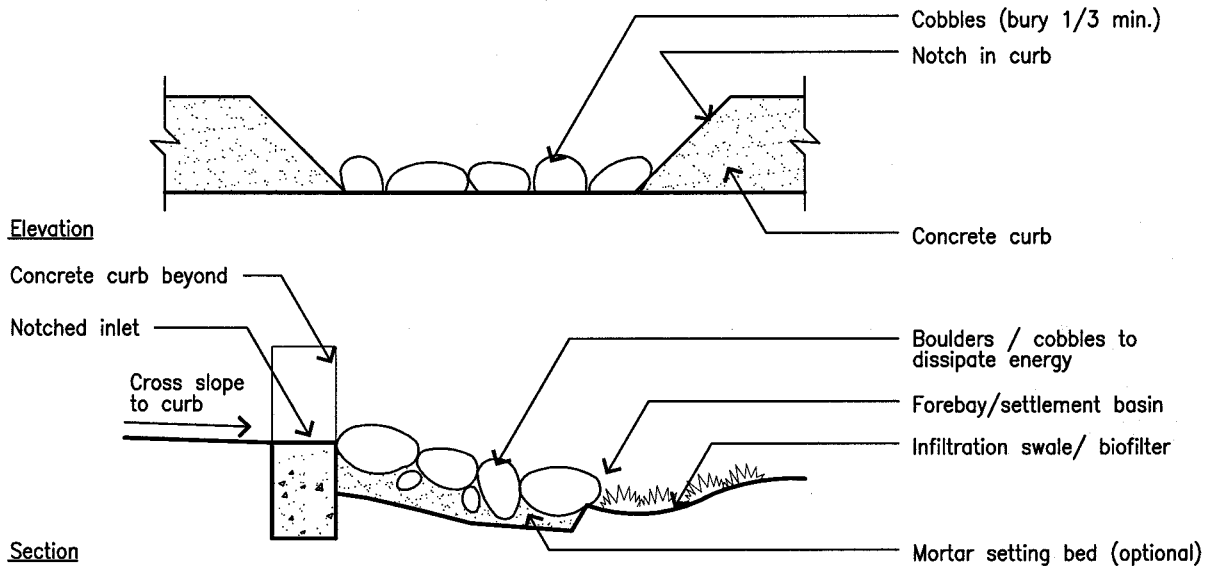
Economics

- Narrower street section and elimination of curb and gutter reduces initial street construction costs significantly.
- Reduced roadway pavement width and increased infiltration in gravel shoulders reduces or eliminates need for underground stormdrain system.
- Landscaped shoulder with surface stormdrain elements adds moderate landscape maintenance cost.
- Properties on narrower streets with tree-lined landscaped parkways typically command higher values than those on wider treeless streets.

Examples/resources

- Institute of Transportation Engineers (ITE) “Traditional Neighborhood Development Street Design Guidelines,” 1997.
- Skinny Streets program, Portland, OR.
- Residential streets, Atherton, CA.
- Neighborhoods built before WWII.

Urban curb/swale system



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Urban curb/swale systems are a hybrid of standard urban curb and gutter with a more rural or suburban swale drainage system. It provides a rigid pavement edge for vehicle control, street sweeping, and pavement protection, while still allowing surface flow in landscaped areas for stormwater quality protection.

Characteristics

- Runoff travels along the gutter, but instead of being emptied directly into catch basins and underground pipes, it flows into surface swales.
- Stormwater can be directed into swales either through conventional catch basins with outfall to the swale or notches in the curb with flowline leading to the swale.
- Swales remove dissolved pollutants, suspended solids (including heavy metals, nutrients), oil and grease by infiltration.

Applications

- Residential developments, commercial office parks, arterial streets, concave median islands.
- Swale system can run either parallel to roadway or perpendicular to it, depending on topography and adjacent land uses.

Design

- Size curb opening or catch basin for design storm.
- Multiple curb openings closely spaced are better than fewer openings widely spaced because it allows for greater dissipation of flow and pollutants.
- Provide energy dissipators at curb notches or catch basin outfall into swale.
- Provide settlement basin at bottom of energy dissipator to allow for sedimentation before water enters swale.

Maintenance

- Annual removal of built-up sediment in settlement basin may be required.
- Catch basins require periodic cleaning.
- Inspect system prior to rainy season and during or after large storms.

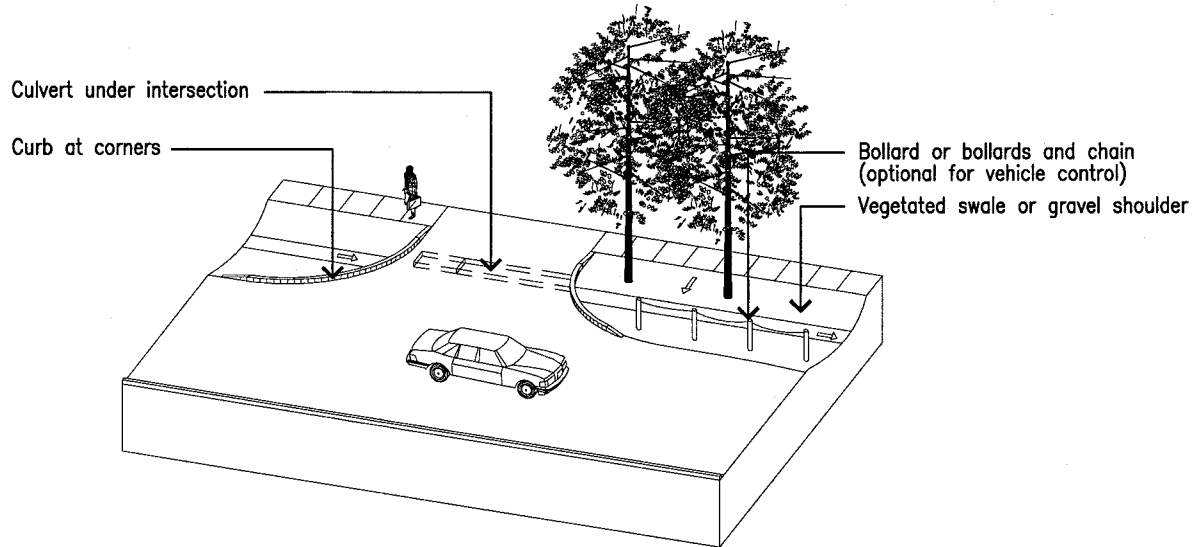
Economics

- Cost savings through elimination of underground storm drain network.
- Cobble-lined curb opening may add marginal cost compared to standard catch basin.
- Swale system requires periodic landscape maintenance.

Examples/resources

- Residential street network, Village Homes subdivision, Davis, CA.
- Dual-drainage system, Folsom, CA.

Rural swale system



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Rural swale systems are a combination of street design elements that allow for surface drainage while simultaneously protecting the roadway edge, organizing parking, and allowing for driveway access and pedestrian circulation.

Characteristics

- Shoulder can be designed to accommodate parking or to serve as a linear swale, permitting infiltration of stormwater along its entire length.
- Runoff from the street is not concentrated, but dispersed along its entire length, and build-up of pollutants in the soil is minimized.

Design

- Concrete curb and gutter not required.
- Ensure that culverts under intersections drain, to avoid standing water and resulting septic condition.

- Provide concrete curb at intersection radii to protect roadway edge and landscape area from turning movements.
- Crown street to direct runoff to shoulders. If drainage is provided on one side only, then provide cross-slope towards swale.
- Protect pavement edge with rigid header of steel, wood or a concrete band poured flush with the street surface.
- If parking is not desired on the shoulder, or if it needs to be organized, install bollards, trees or groundcovers along the shoulder to prevent vehicle trespass.
- Central medians can be used to divide traffic for safety or aesthetics.

Maintenance

- Surface systems require periodic maintenance and inspection.
- Maintenance for surface systems is different than most urban Public Works Departments currently practice, and employee retraining may be required.
- Surface drainage systems are easier to monitor and clear than underground systems, because problems, when they occur, are visible and on the surface. This eliminates the need for subsurface inspection or street excavation.

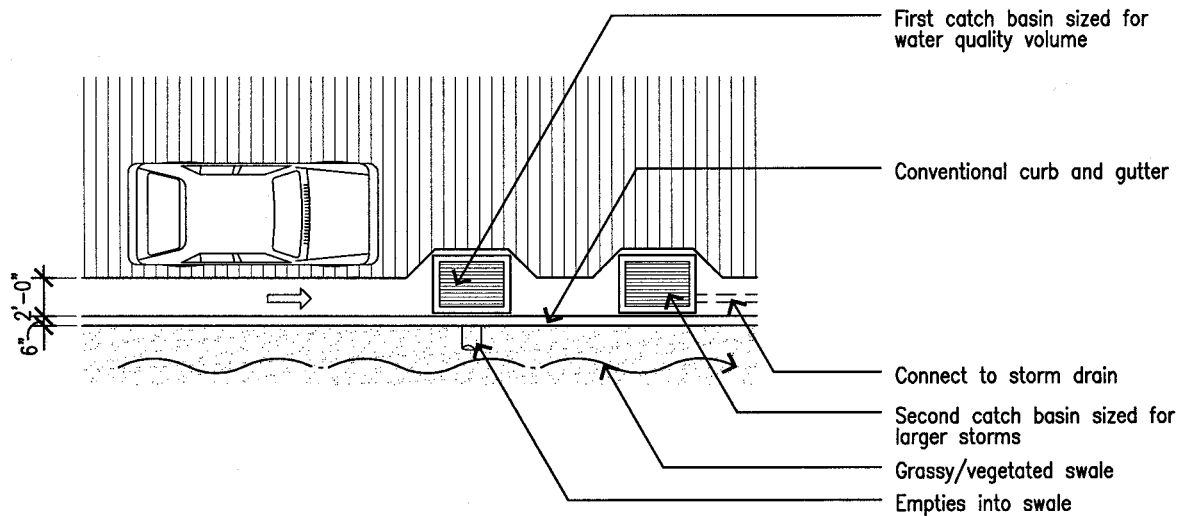
Economics

- Surface swales are less costly to install than underground pipe systems, but may have higher on-going maintenance costs.

Examples/resources

- City of Folsom, CA.

Dual drainage system



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Dual drainage systems provide a pair of catch basins at each inlet point— the first is sized to direct the water quality volume into a landscaped infiltration area, and the second collects the overflow of larger storms and directs it to the storm drain system.

Characteristics

- “Treatment train” approach provides for both water quality and flood protection.
- Separation of water quality volume from larger storms provides a bypass that prevents flushing of sediment and pollutants in vegetated swale during larger storms.
- Appearance of typical urban street.

Applications

- Streets in residential or commercial developments, arterial streets.
- Swale can be located on shoulder or in concave median.

- Not appropriate for industrial areas due to the potential of spills.

Design

- Locate two catch basins adjacent to each other.

First (uphill) catch basin Design outlet pipe to accommodate the water quality volume and direct to adjacent grass or vegetated swale. When first catch basin is full (because inflow exceeds volume of outlet pipe), water will flow past first basin inlet and enter second catch basin.

Second (downhill) catch basin Design to accommodate larger volumes and connect outlet to underground storm drain system or to detention pond.

- Culverts must be provided to carry swale under cross streets and drive-ways.

- Design swale to accommodate water quality volume.
- If swale is planted with turf grass, provide supplemental irrigation to maintain turf.
- For additional information on swale design, see Technical Detail 6.6a Grass/vegetated swales.

Maintenance

- Perform standard maintenance practices on swale and catch basins.

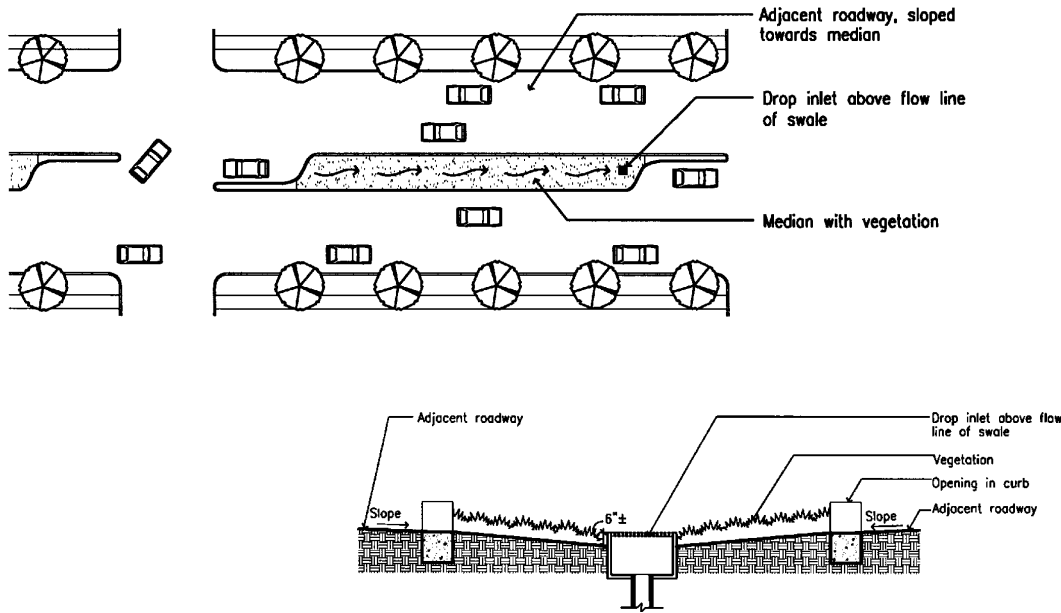
Economics

- Dual drainage system is more expensive to install and maintain than other solutions because of multiple elements.

Examples/resources

- City of Folsom, CA, Highway 50 at Folsom exit. Contact City Engineer.

Concave median



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Concave medians. Conventional medians are normally designed as a convex surface to shed water onto adjacent pavement and into a curb and gutter system. Concave medians reverse this relationship by depressing the median surface slightly depressed below the adjacent pavement section and designing the median to receive runoff.

Characteristics

- Provides safety and aesthetic functions of traditional convex medians while accommodating stormwater infiltration.
- Helps to disconnect impervious street surface from storm drain system by directing street runoff into landscaped or aggregate-filled median for infiltration.
- Can be designed as a landscaped swale or turf-lined biofilter to treat first-flush runoff, which carries a high concentration of oils and other pollutants off the street.

Design

- Adjacent roadway design must provide cross-slope into medians.
- Runoff from street can be directed into swale by sheet flow or curb inlets.
- Concave medians must be sized to accommodate the water quality volume, and planting must be designed to withstand periodic inundation.
- Catch basin and underground storm drain system may be required for high flows, depending on the available area for infiltration and retention.
- Set catch basin rim elevations just below the pavement elevation, but above the flow line of the infiltration area so that the water quality volume will collect in the swale before overflowing into the underground system.

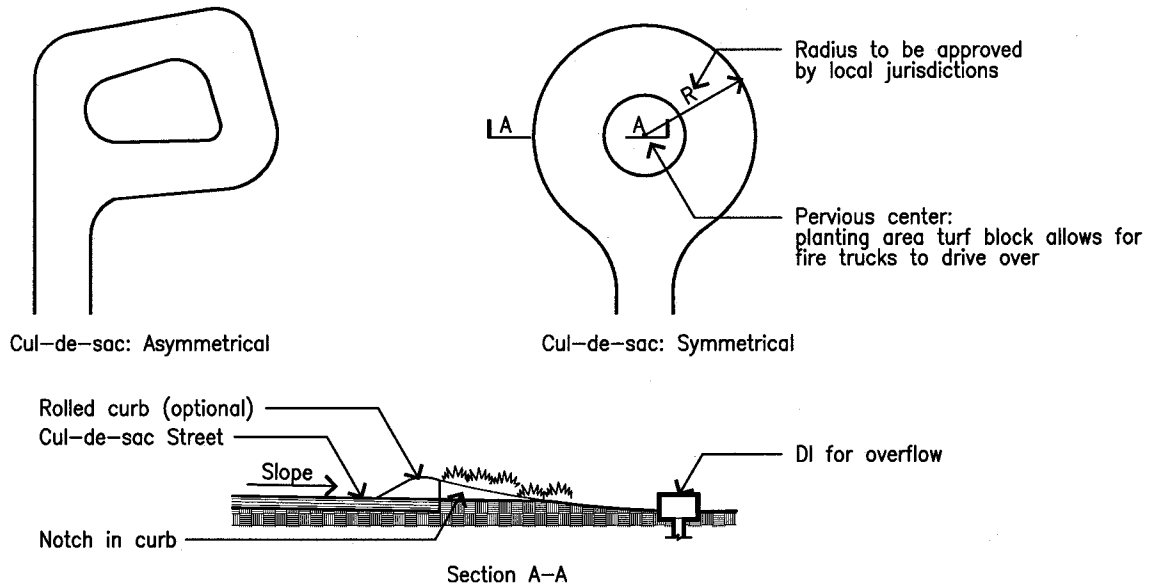
Maintenance

- Landscaped concave medians have maintenance requirements similar to landscaped convex medians.
- Some maintenance staff retraining may be required to facilitate maintenance of swales or other stormwater detention elements.

Economics

- Costs are similar to convex landscaped medians.

Cul-de-sac



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Cul-de-sac streets are dead-end streets that require turnaround areas large enough to accommodate large trucks and emergency access vehicles.

Characteristics

- Conventional cul-de-sacs are paved across their entire diameter. This large impervious area adds to environmental degradation by increasing runoff and creating a heat island at the front of adjacent land uses.
- A turnaround with a central concave landscaped space or other pervious surface can meet fire department access requirements and create an opportunity for stormwater infiltration or detention.
- A landscaped area in the center of a cul-de-sac can reduce impervious land coverage by 30 to 40%, depending on configuration, while maintaining the required turning radius.

Applications

- Appropriate for cul-de-sac streets in residential, commercial, and institutional settings.

Design

- Street termination requires turnaround area large enough to accommodate large trucks, such as occasional moving vans and emergency access vehicles (fire departments often require 60 feet or greater diameter turnarounds).
- Some local fire departments may require the center landscaped area to accommodate fire trucks. This can be achieved by providing a permeable load bearing surface such as turf-block, and eliminating woody plant materials such as trees from the planting area.
- Asymmetrical cul-de-sac design is more rural than conventional round cul-de-sac design.
- Curb with slots may be needed to allow run-on from the street while keeping vehicles off landscaping.

Maintenance

- Similar to other planted medians.

Economics

- Cost of extending storm drain the length of the cul-de-sac may outweigh the savings gained from reduction of paved area.
- Landscaping in center island may add costs for irrigation, planting, and periodic maintenance.

8.3 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.

T*he 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 a conventional underground storm drain system, parking lots typically generate a great deal of directly-connected impervious area. Because the cars sitting in these lots shed hydrocarbons, heavy metals and other pollutants, parking lots are a primary collector and conveyor of urban runoff pollution.*

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.

Parking Lots

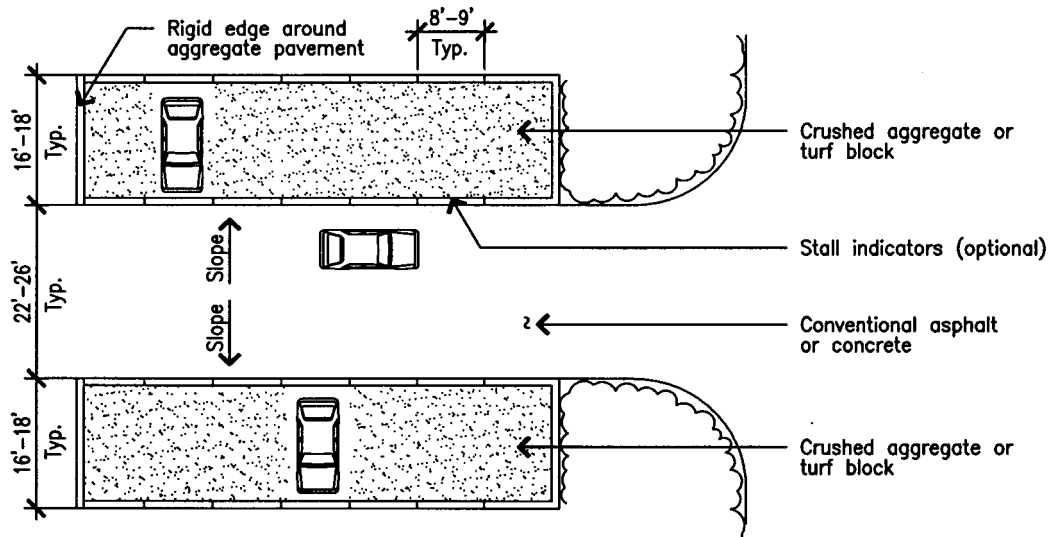
Hybrid parking lot

Parking grove

Overflow parking

Porous pavement recharge bed

Hybrid parking lot



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Hybrid parking lots differentiate paving, combining impervious aisles with permeable stalls. Impervious aisles are designed to carry moving vehicle traffic and accommodate turning movements. Permeable stalls are designed for stationary or very slow moving cars. There are many possible combinations of materials.

Characteristics

- Hybrid lot 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.
- Differentiation between aisles and stalls can mitigate the overall visual impact of the parking lot.

Applications

- Commercial areas, offices, multi-family housing, hotels, restaurants.
- Selection of permeable pavement material depends on use. Porous asphalt, pervious concrete or unit pavers are

recommended for stalls in areas with high turnover, such as restaurants. Areas with low turnover, such as hotels, office buildings, and housing can use crushed aggregate for stalls.

- Variable permeability, depending on pavements chosen.
- High ground water or lack of deep, permeable soils may limit applications.

Design

- Keep permeable pavement areas relatively flat (slope $\leq 5\%$). See Section 6.1 Permeable pavements.
- Aisles are constructed of conventional asphalt or concrete suitable for heavier traffic use, speeds between 10 and 20 mph, and designed to support the concentrated traffic of all vehicles using the lot.
- Stalls are constructed of a permeable pavement, such as open-graded crushed aggregate, open-celled unit pavers, turfblock, porous asphalt, or

pervious concrete.

- Slope aisles into adjacent permeable stalls.
- Subdrain or overflow drainage may be required depending on design storm and underlying soils.
- Stall markings can be indicated with wood headers laid in field of permeable pavement, change in unit paver color, concrete bands or pavement markers ("botts dots"), depending on the material used.
- Designated handicapped stalls must be made of an ADA compliant pavement.

Maintenance

- Periodic weed control, sweeping, and regrading required for gravel stalls.
- Irrigation, fertilizer, weed control, and mowing required for turf block stalls.
- Pressure hosing or vacuum sweeping may be required for pervious concrete or porous asphalt stalls.

Hybrid parking lot, continued

Economics

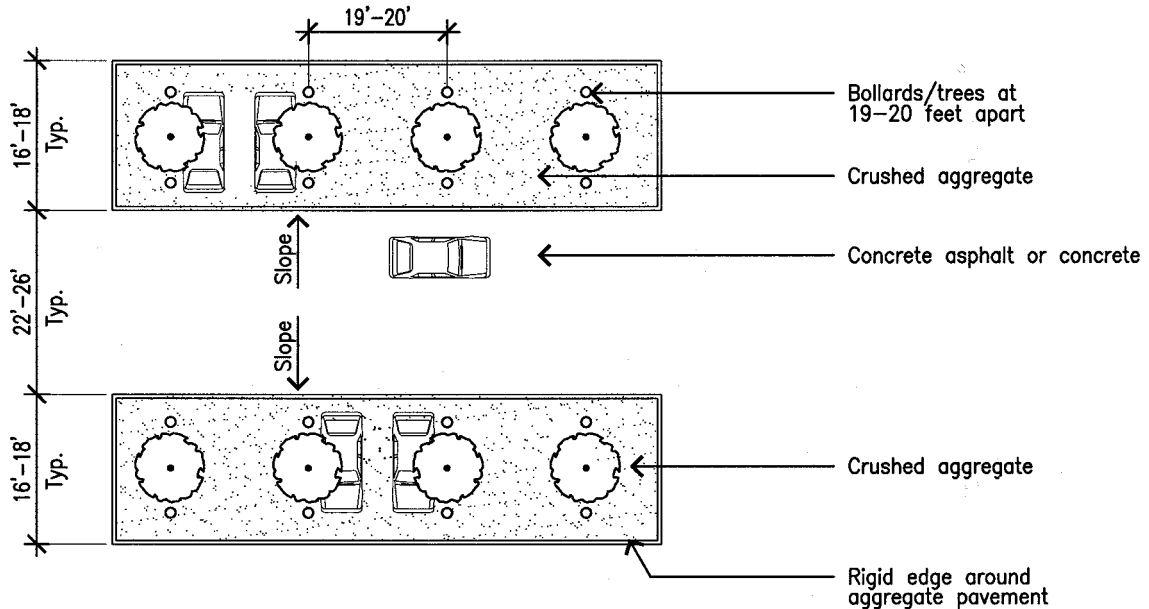
- Reduction of overall impervious surface coverage may eliminate or reduce need for underground drainage system.
- Construction cost will depend on materials chosen. A hybrid lot of conventional asphalt aisles with crushed aggregate stalls will be lower cost than a lot entirely paved in asphalt. A hybrid lot of conventional asphalt aisles with unit pavers stalls will be higher cost than a lot entirely paved in asphalt.

Examples/resources

- Parking lot. Medford Village, NJ.

Parking lots

Parking grove



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Parking groves, a variation on the hybrid parking lot design (See 6.3a), use a grid of trees and bollards to delineate parking stalls and create a shady environment. The permeable stalls reduce impervious land coverage while the trees reduce heat island effect and improve soil permeability.

Characteristics

- Parking grove not only shades parked cars, but presents an attractive open space when cars are absent.
- Permeability depends on the type of pavement used.
- Reduces impervious land coverage.

Applications

- Best in locations where the users of the parking lot are a consistent group of people (such as multi-family housing or an office building) who become familiar with parking between the trees.
- Best in situations where vehicles park for long periods of time, such as hotels, housing, offices.

- Not recommended for high turnover lots, such as restaurants and commercial areas because of additional care needed to navigate around trees.

Design

- Parking stalls must be oversized to accommodate thickness of bollards and trees. A grid of trees/bollards spaced approximately 19 feet apart allows two vehicles to park between each row of the grid (9.5 foot space per stall, compared to the standard 8.5 to 9 foot space per stall). A grid of 28 to 30 feet allows for three cars between each pair of trees.
- Set trees/bollards at least three feet in from end of stall to allow for turning movements into and out of stall.
- Trees should be protected during the establishment period with double staking of 3" diameter wood stakes. Align stakes along implied stall line.
- Bollards may be omitted if proper tree staking is provided during establishment period.

- Metal tree cages are not recommended because they are easily damaged and can scratch cars.
- Trees should be selected for high, horizontal branching structure, and should not be prone to limb breakage (such as Eucalyptus spp. and Grevillea robusta), or insects that secrete honeydew (such as Celtis).
- Provide irrigation to trees as required.

Maintenance

- Requires tree pruning and maintenance to ensure clearance of vehicles.
- Trees may occasionally be hit by cars, but will heal themselves under normal circumstances.

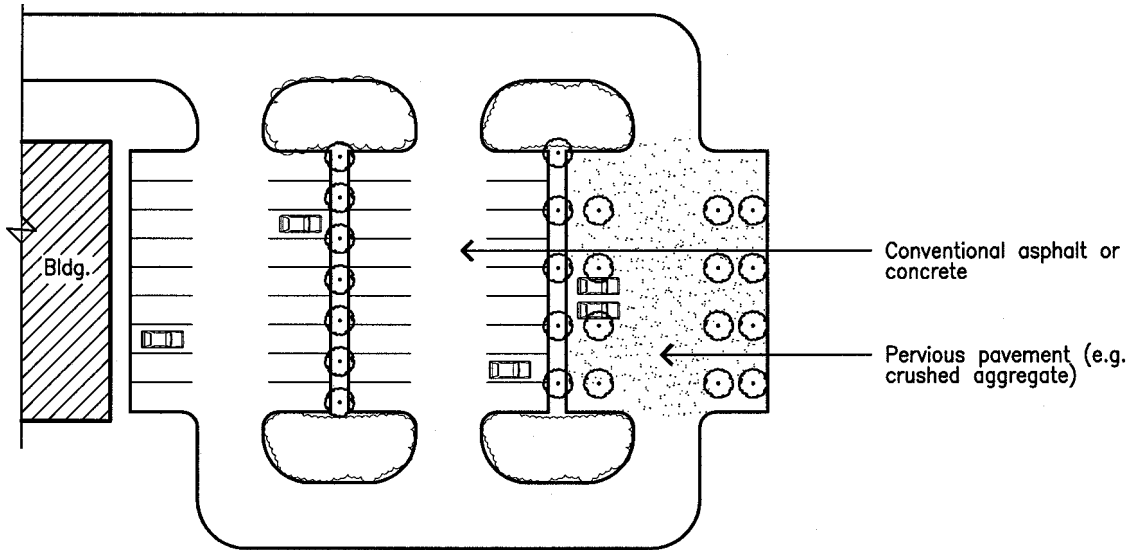
Economics

- More expensive to construct and maintain than standard parking lots.

Examples/resources

- Seaside Motel Auto Court, Seaside, FL.

Overflow parking



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Overflow parking design differentiates between regular and peak parking demands, constructing the regular demand parking stalls with traditional impervious materials and constructing peak parking stalls of a different, more permeable, material.

Characteristics

- Overflow area can be pervious materials such as turf block, crushed stone, unit pavers on sand, and can be designed to break up an expanse of continuous parking lot.
- Permeability depends on pavement used.

Applications

- Large parking lots with variable capacity needs such as shopping malls, conference centers, office complexes, amusement parks, sport facilities.

- Visitor parking areas in multifamily residential developments or office complexes.
- Facilities with infrequent but extensive peak parking needs, such as churches, sports arenas, and conference centers.

Design

- Must be designed to accommodate volume of overflow parking.
- In many uses, regular parking demand accounts for approximately two-thirds of total, with one-third accommodated as overflow.
- Irrigation may be necessary if overflow parking is turf block.

Maintenance

- Maintenance depends on pavement selected.

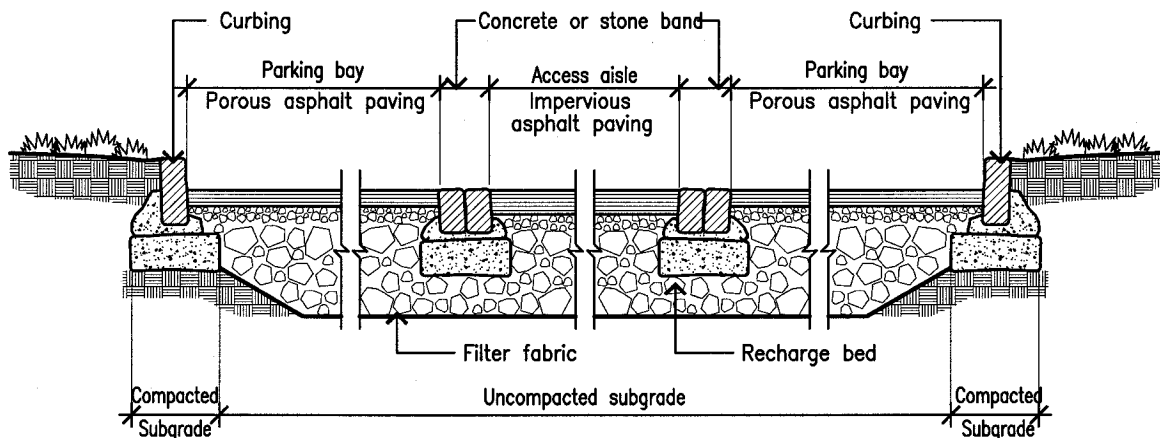
Economics

- Cost depends on pavement selected and overall design.

Examples/resources

- Gravel overflow parking at Nordstrom parking lot. Corte Madera, CA.
- Orange Bowl parking lot, FL.

Porous pavement recharge bed



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional. Detail adapted from Andropogon Associates.

Porous pavement recharge beds underneath parking lots are gravel beds that receive and store infiltration.

Characteristics

- Underground system eliminates the possibilities of mud, mosquitoes and safety hazards sometimes associated with ephemeral surface drainage.
- Provides for storage of large volumes of runoff, which is directed underground by means of perforated distribution pipes.
- Constraints include soil infiltration rates, depth to water table and bedrock, and traffic type and volume.

Applications

- Underneath parking lots generally in areas where land values are high and the need to control runoff is great.

Design

- 2-1/2" porous asphalt paving on clean gravel topcourse.
- Recharge and storage basin of clean open-graded crushed stone with 40% void space.
- Filter fabric placed on floor and sides of recharge bed following excavation allows water to pass readily, but prevents soil fines from migrating up into rock basin, reducing effective storage area of recharge bed.
- Design an unpaved edge of porous pavement, and top off with stone (such as river stone), place wheelstops at edge. This functions as an emergency overflow inlet around perimeter of parking bay.
- Limit porous surfaces to parking areas receiving least wear and tear.
- Soil layer of 4 feet or more with percolation rate of 0.5 inches per hour or more required; must be field tested.

- Direct all sediment-laden runoff from impervious surfaces (e.g., roof tops, roads, parking areas, walkways, etc) away from porous pavement/recharge bed or pretreat to eliminate sedimentation.
- Prevent failures by implementing strict erosion/sediment control during construction (sediment that erodes or is tracked on to the surface can clog void spaces in pavement and prevent stormwater from entering the recharge bed below).

Maintenance

- Vacuum sweeping or pressure hosing recommended twice per year under normal circumstances.

Economics

- Expensive, requires extensive engineering.

Examples/resources

- Morris Arboretum, Philadelphia, PA.
- Automatic Data Processing corporate offices, Philadelphia, PA.

8.4 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%.

There are several ways to reduce the impact of driveways on water quality. These include directing runoff from an impervious driveway to a landscaped infiltration area, constructing the driveway from a permeable pavement, and reducing the overall amount of pavement provided.

Driveways

Not directly-connected impervious driveway

Gravel driveway

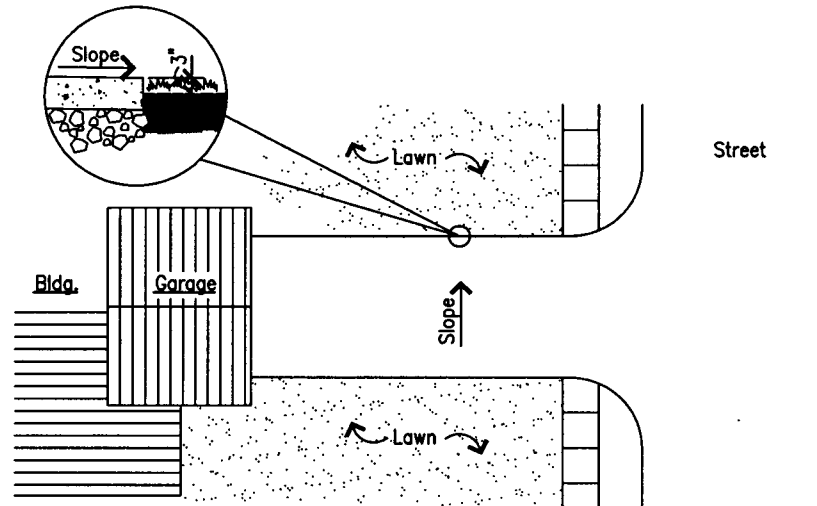
Unit pavers on sand

Paving only under wheels

Flared driveways

Temporary parking

Not-directly connected impervious driveway



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Not directly-connected impervious driveway slopes the surface to drain into an adjacent turf or groundcover area, rather sloping towards the curb and gutter in the street as commonly done.

Characteristics

- Appearance is the same as conventional driveway.
- Pollutants are dispersed and cleansed in the soil as driveway runoff passes through a permeable landscaped area.

Applications

- Suitable for all driveways with sufficient adjacent landscape areas.

Design

- Cross slope must be greater than longitudinal slope to direct runoff into adjacent landscape
- Adjacent landscaped area must be sized to accommodate the water quality volume.

- Edge of driveway must be approximately 3 inches above the vegetated area, so that vegetation or turf doesn't block sheet flow from driveway onto soil.

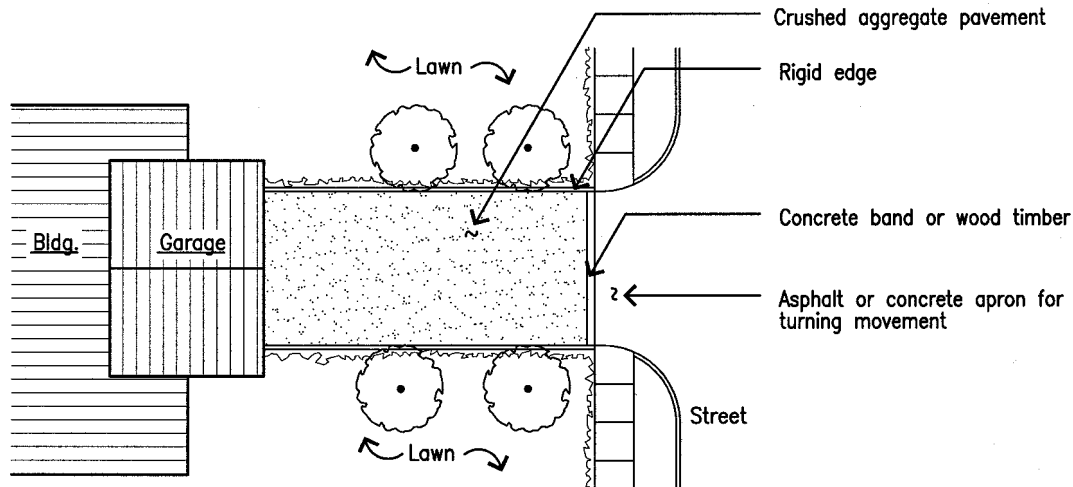
Maintenance

- Edging of adjacent lawn is important to allow unimpeded flow of runoff from driveway onto lawn.

Economics

- Cost is same as conventional driveway.

Crushed aggregate driveway



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Crushed aggregate driveway.

Crushed stone and other granular materials can make a relatively smooth permeable pavement suitable for the low speeds and volumes of typical residential driveways.

Characteristics

- Aesthetic can be formal or rural depending on design and materials.
- Crushed aggregate driveways have a distinctive “crunchy” sound reminiscent of traditional country estates and homes.

Applications

- For driveways that are lightly used by very slow moving vehicles, and those that serve single family homes.
- Not suitable for multi-use driveways such as those that accommodate children’s play.
- Flat sites (slope ≤ 5%).

Design

- Rigid edge such as wood header, concrete, metal, or brick band desirable to contain aggregate material and to maintain surface strength.
- Provide a non-granular apron at intersection of driveway with street to accommodate turning movements.
- Provide a concrete band or wood timber at transition between apron and crushed aggregate driveway to absorb impact of repeated wheel crossings.
- Use open-graded crushed aggregate (such as 3/8” to 3/4” granite) rather than rounded stones such as pea gravel. Angles of the crushed stone form a matrix that holds the granular material in place, able to bear the load traffic without substantial displacement.
- Minimize compaction of finished grade and subgrade. Roll surface of aggregate sufficiently to stabilize the stone.

- Open-celled plastic matrix can be used to provide added stability of crushed aggregate.

Maintenance

- Weed control may be needed periodically.
- Periodic replenishment of aggregate may be required.

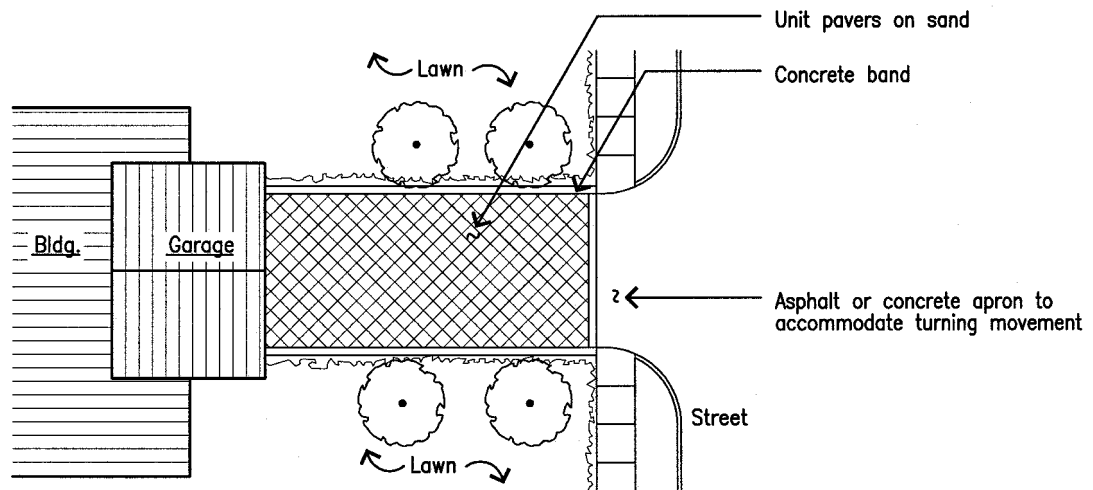
Economics

- Least cost of all pavement materials.
- \$1 to \$3 per square foot, depending on design.

Examples/resources

- Open-celled matrixes are available from Gravelpave, GeoWeb by Presto.

Unit pavers on sand driveway



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Unit pavers on sand are discrete units that are set in a pattern on a prepared base and bound by a rigid edge to form a pavement suitable for a driveway.

Characteristics

- A pavement of brick or unit pavers on sand can make the driveway more integrated with the garden rather than an extension of the street penetrating deep into the garden space.
- Available in a variety of natural and synthetic materials, such as brick, natural stone, cast concrete.
- Runoff coefficient of open celled units: 0.10-0.35 (more permeable if larger voids, solid units: 0.10-0.20. Infiltration rates are higher during lighter, lower intensity rains.

Applications

- Residential driveways.
- Accent to traditional asphalt in low volume commercial driveway.
- Flat sites (slope \leq 5%).

Design

- Because the unit pavers are laid loose, the field must be enclosed by a rigid frame. Concrete bands, metal or plastic edging are commonly used.
- To maximize permeability, use an open-graded crushed rock base course (not rounded pea gravels, no fines).
- May not be suitable on expansive soils without special subgrade preparation.

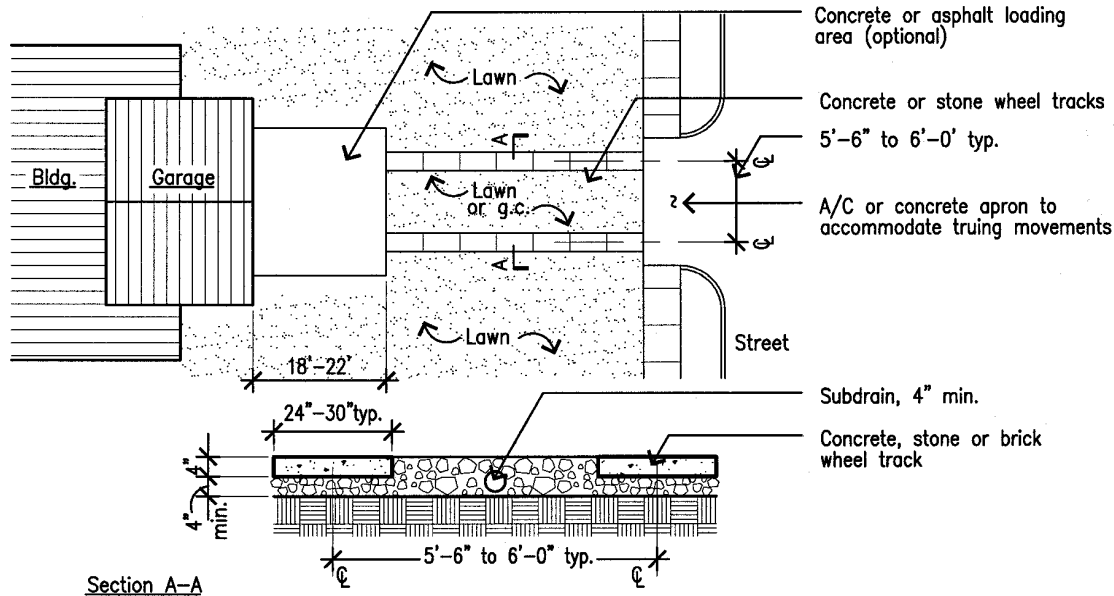
Maintenance

- Longevity ensured by locating in low-erosion conditions, quality construction, and installation of good base layer.
- Easy to repair, since units are easily lifted and reset.
- Periodically add joint material (sand) to replace material that has been moved/worn by traffic or weather.
- Occasional weed suppression may be required.

Economics

- Installation cost \$9-15 per square foot
- More expensive than conventional concrete or asphalt, less expensive than unit pavers on slab.
- Increased construction and maintenance costs can be offset by improved aesthetic and market appeal compared to conventional asphalt or concrete driveways.

Paving only under wheels



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Paving only under wheels. Paving only under the wheel tracks, with the area between landscaped reduces impervious land coverage, also called a “Hollywood driveway.”

Characteristics

- Center strip planted with grass, groundcovers, or filled with gravel.
- A driveway of two paved wheel tracks can reduce impervious surface coverage by 60 to 70% compared with a single lane paved driveway.

Applications

- Residential, low density single family, duplex, mobile home.
- Best in straight driveways, not recommended for curving driveways.

Design

- Wheel tracks should be wide enough to accommodate variability in driving and vehicle widths.
- Wheel tracks must be designed to support vehicle loads, usually concrete or mortar-set unit pavers such as stone or brick.
- A perforated drain line buried between wheel tracks to collect and direct runoff may be added in soils with low infiltration rates.
- If ground cover or grass is selected for center strip, irrigation system must be provided, and parked vehicles must be moved periodically so that a single location is not continuously shaded.

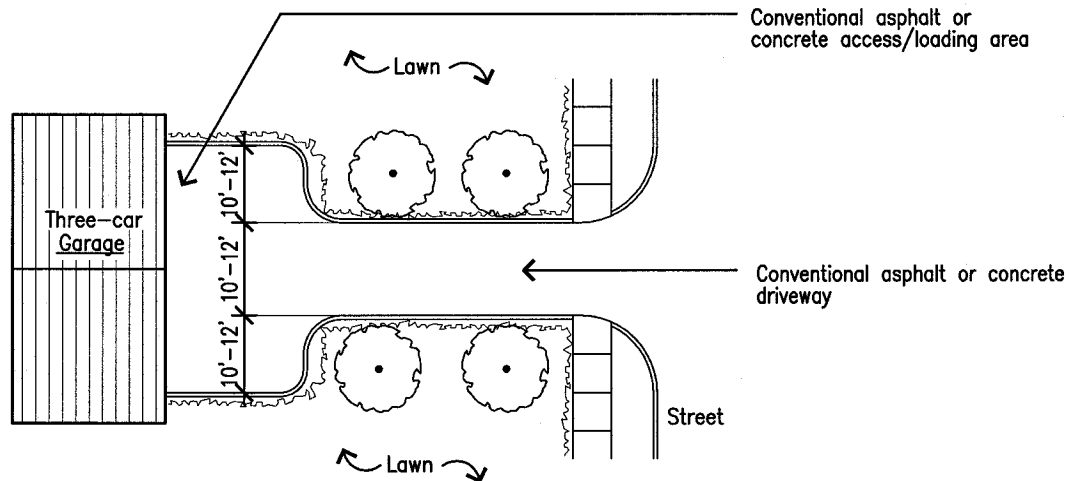
Maintenance

- Area between wheel tracks requires maintenance.
- If area between tracks is planted with lawn, additional edging will be needed.

Economics

- Reduced pavement area reduces construction costs.
- Complex detailing, inclusion of landscape planting and irrigation can add significant costs.

Flared driveways



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Flared driveways use a single lane to provide access to multiple-car garages by flaring the area in front of the garage.

Characteristics

- The approach to the garage from the street is a single lane, adequate to accommodate the relatively infrequent vehicle trips, while the portion of the driveway at the garage is widened to provide access to all garage doors.
- Reduces impervious surface area compared to multi-lane driveway extending entire length from garage to street.

Applications

- Appropriate for multi-car garages or single family homes with adjacent garages that do not require the full multi-lane width along their entire length.

Design

- Typical driveway design, single lane width at street, and flare to serve garages that are shared.
- Provide adequate depth in front of multi-car garage for vehicle parking and maneuvering.

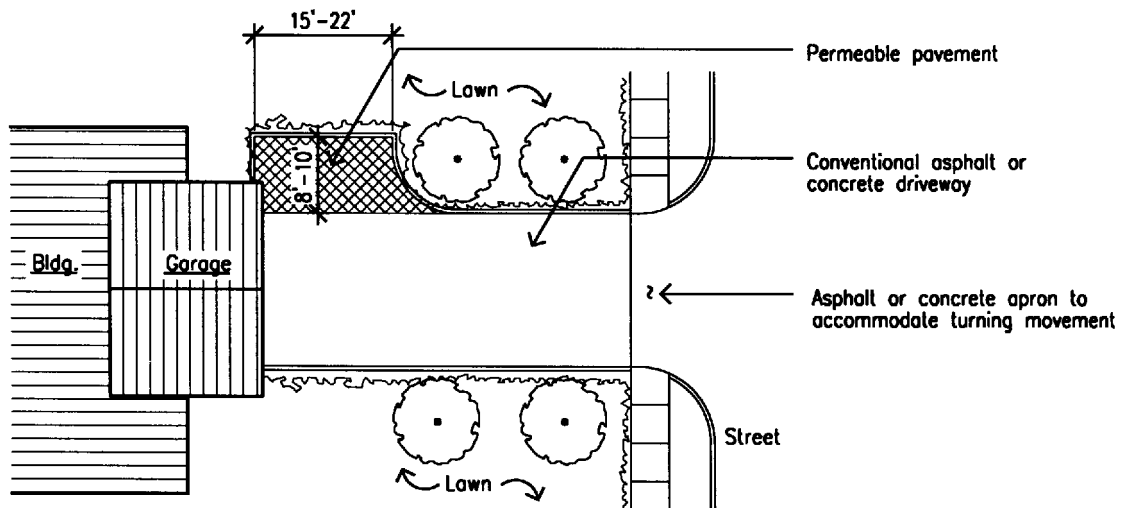
Maintenance

- Same as standard driveway.

Economics

- Reduces overall pavement cost.

Temporary parking



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Temporary parking is paved with a permeable surface, such as turf-block or open-celled unit paver, and maintained as a landscaped surface.

Characteristics

- Appears and functions as green space or patio for the majority of the time when not used for parking.
- Runoff coefficient depends on the type of pavement used.
- Reduces impervious surface area.

Applications

- Residential driveway applications, such as RV or trailer parking.
- Areas where parking or loading access is required infrequently.
- Guest parking areas.

Design

- Must be designed to support vehicle loads.

Maintenance

- Turf-block requires similar maintenance as conventional lawn.
- Brick or unit pavers require periodic weed suppression.

Economics

- Higher initial cost than asphalt or concrete parking areas.
- Increased construction and maintenance costs can be offset by improved aesthetic and market appeal compared to conventional asphalt or parking areas.

8.5 Buildings

By definition, buildings create impervious land coverage. There are, however, techniques to treat runoff from individual buildings and to collect rooftop runoff for infiltration into the soil.

Roof runoff is typically either channeled in gutters and downspouts or allowed to sheetflow off the roof. Downspouts focus runoff, concentrating the entire watershed of the roof into one or a few points. This concentrated flow can be stored and slowly infiltrated into the soil in a controlled manner through dry-wells, cisterns, or by directing flow into landscape infiltration/detention areas.

Sheet runoff from roofs can be directed and infiltrated onto adjacent landscape areas through grading, mulching, and plant selection.

Buildings

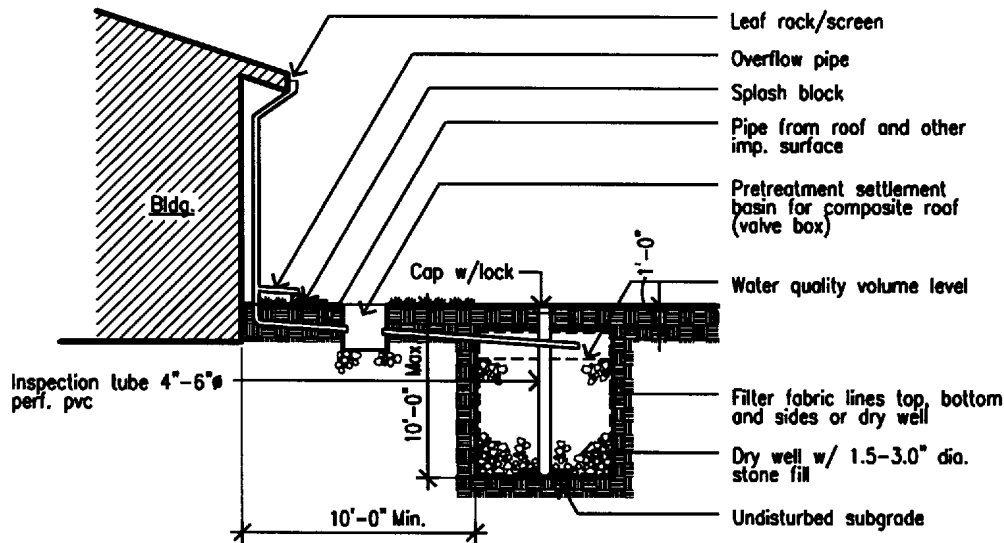
Dry-well

Cistern

Foundation planting

Pop-up drainage emitters

Dry-well



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Dry-well. A dry-well is a subsurface basin to which runoff is diverted for infiltration. The roof downspout is connected to the dry-well, allowing runoff to be stored and slowly infiltrated.

Characteristics

- Compact.
- Hidden from view, has no effect on aesthetics.

Applications

- Not appropriate for slopes >40% or areas with expansive soils.
- Many agencies have policies regarding dry wells because of concerns that include migration of pollutants into groundwater, or dumping of pollutants into drywell. Most jurisdictions permit drywells that are connected directly to roof downspouts and are less than ten feet deep. Check local regulations.

Design

- Confirm requirements with local municipal ordinances. These may include

overall depth, as well as setbacks from structures, property lines, water supply wells, groundwater level, septic drainfields, and sensitive areas.

- Dimension calculations assume:
 - 1) Total volume runoff generated by roof in a design storm (e.g. 10 year, 24-hour, etc.) must be stored or infiltrated by the system during the storm.
 - 2) Infiltration system empty at beginning of storm and full at end.
 - 3) Rainfall and infiltration rates constant for duration of storm, including a safety factor.
- Subgrade must be relatively permeable (not appropriate for clay).
- Requires excavation filled with drain rock and wrapped top, sides and bottom with filter fabric. Excavation is sized to accommodate water quality volume storm, accounting for 38-40% void space of gravel fill.
- A buried catch basin (concrete, plas-

tic, or metal) or large diameter pipe with open bottom set on end can be used to contain drain rock.

- Roof downspouts are attached to the dry well, an overflow pipe is provided for runoff in excess of water quality volume.
- Provide perforated observation pipe (such as a 6" diameter PVC) to allow for inspection and maintenance.
- Provide pre-treatment sedimentation basin for composite roofs. This can be a small plastic valve box with open bottom.

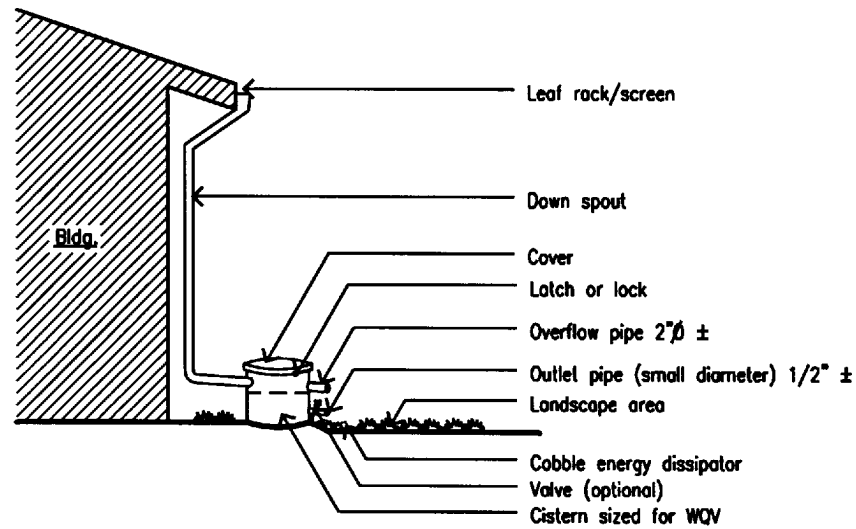
Maintenance

- Requires inspection at beginning of rainy season.
- Remove sediment from sedimentation basin prior to rainy season.

Economics

- Relatively inexpensive to construct and maintain.

Cistern



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Cistern. A cistern is an above ground storage vessel that is directly connected with the roof downspout. Water is slowly released with either a manually operated valve or a permanently open outlet.

Characteristics

- 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.
- Reduces peak runoff and allows sediment to settle.
- Provides more infiltration benefits than connecting directly to storm drain.

Applications

- Residential, commercial, office buildings.

Design

- Manually operated valve can be closed to store stormwater for irrigation use or infiltration between storms.
- Cistern must be covered to prevent mosquitoes from breeding.
- Permanently open outlet must be sized appropriately. If it is significantly smaller than the size of the downspout inlet (approx. 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, mitigating the peak flow runoff from impervious rooftops, especially for the frequent, small storms.
- Size cistern for water quality volume, provide overflow for larger storms.

- Provide secure cover or ≤ 4 " top opening if holding more than 6" depth of water, to prevent small children from gaining access to the standing water.
- Provide screen on gutter and intake of outlet pipe to minimize clogging by leaves and other debris.

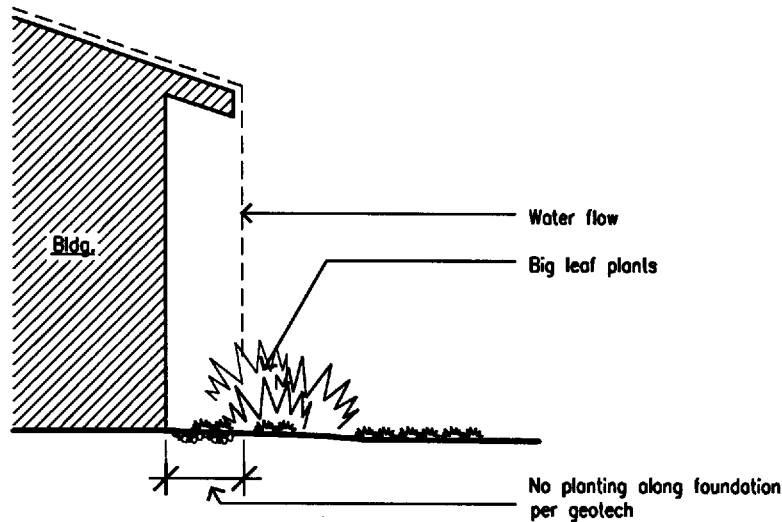
Maintenance

- System requires regular monitoring and cleaning.
- Maintenance required to ensure that system is not clogged by leaves or other debris.

Economics

- Low installation cost.

Foundation planting



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Foundation planting. Landscape planting around the base of the eaves can reduce the physical impact of water on the soil and provide a subsurface matrix of roots that encourage infiltration.

Characteristics

- Foundation planting serves function of to provides increased opportunities for stormwater infiltration.
- Planting protects the soil from erosion caused by concentrated sheet flow coming off the roof, reducing the amount of sediment in urban runoff.

Applications

- For buildings that do not use a gutter system.

Design

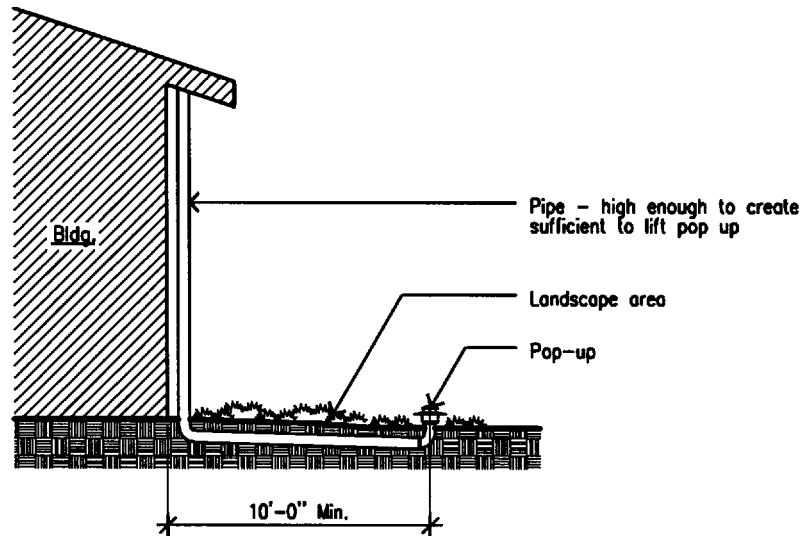
- Locate plants at the roof drip-line.
- Select plants with high capacity for vertical water storage.

- Select plants with leaf architecture that intercepts rainwater and traps it for eventual evaporation.
- Select plants sturdy enough to tolerate the heavy runoff sheet flows, and periodic soil saturation.
- Provide mulch cover in planting bed to protect soil from impact of falling rainwater and to increase soil water-holding potential.
- Protect perimeter of foundation as required by local soil conditions.

Maintenance

- Regular garden maintenance.

Pop-up drainage emitter



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Pop-up drainage emitters allow water collected by downspouts and roof gutter systems to flow through a drainage pipe away from structural foundations, and “pop-up” to disperse in lawn or landscaped areas.

Characteristics

- Emitter is opened by the hydrostatic pressure flowing through the drain pipe. As flow diminishes, the emitter closes again.
- Blends into the surrounding landscape; appearance similar to standard pop-up sprinkler.
- Sheet flow of runoff allows for infiltration.

Applications

- Can use for water captured by standard gutter and downspout system, grates, catch basins, grates and drains.
- Can use to divert water away from erosion-prone or poor drainage areas.
- May be more effective in certain soil types.

Design

- Size emitter(s) according to downspout and watershed (roof area) size.
- Design pipe riser to height required to create head sufficient enough to lift pop-up.
- Design outfall to sheetflow onto vegetated area (such as lawn or groundcover) or suitable landscaped or paved infiltration and drainage system.

Maintenance

- Standard maintenance practices can be used.
- Emitter is only open when water is flowing through the drain pipe, minimizing the risk of debris and rodents entering the pipes.

Economics

- Emitter unit cost \$12-20 each plus pipe.

Examples/resources

- City of Milpitas has info. on the sq. ft. of landscape required per sq. ft. roof.

8.6 Landscape

Landscape solutions for stormwater quality combining site engineering – grading and drainage – with landscape architecture. This presents an opportunity for civil engineers and landscape architects to cooperate on the designs for integration of function and aesthetics.

One concern among developers and property owners is that landscape stormwater infiltration and detention areas will become subject to government regulation as wetlands after they are established.

According to the California Regional Water Quality Control Board, these landscape areas are not classified as jurisdictional wetlands subject to mitigation if their land use is later changed, as long as:

- *the design elements (e.g., swales, ponds) are clearly identified on plans and documentation as stormwater treatment areas (BMPs),*
- *the design elements are not used as mitigation for impacts to other wetlands, and*
- *the design elements do not impact or replace existing wetlands.*

Landscape

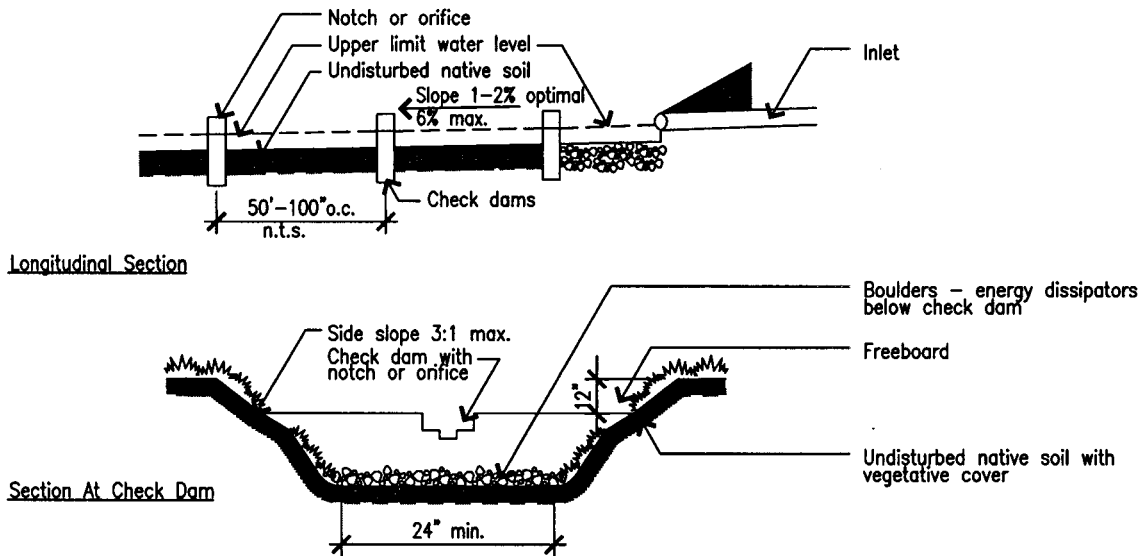
Grass/vegetated swales

Extended detention (dry) ponds

Wet ponds

Plant species selection for infiltration areas

Grass/vegetated swales



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Grass/vegetated swales. An alternative to lined channels and pipes, grass and vegetated swales are vegetated earthen channels that convey and infiltrate water and remove pollutants.

Characteristics

- If properly designed and maintained, swales can last for at least 50 years.
- Can be used in all types of soil. In clay or impermeable soils, swale may require an underdrain to keep maximum water residence time below 24 hours. In sandy or highly permeable soils, swale may require soil amendments to maintain dense turf or vegetation.
- When swales are not holding water, they appear as a typical landscaped area.
- Pollutants and water are filtered by grass/vegetation and removed by infiltration into soil.
- Swales remove suspended solids, the pollutants that are adsorbed onto the

solids (including heavy metals and nutrients), oil and grease.

Applications

- Swales require approx. 1200 square feet minimum per impermeable acre (i.e., they will occupy an area equal to at least 2.75% of site's total impermeable area)
- A single grassy swale can drain approximately 4 acres of land. Multiple swales would be required to drain a larger site.
- Parking lot medians, perimeters of impervious pavements.
- Street and highway medians, edges (in lieu of curb and gutter, where appropriate).
- In combination with constructed treatment systems or sand filters.

Design

- Grass swales move water more quickly than vegetated swales. A grass swale is planted with turf grass; a vegetated swale is planted with bunch grasses, shrubs or trees.

- Pollutant removal effectiveness can be maximized by increasing residence time of water in swale.
- Incorporate systems that temporarily divert flows to allow for maintenance.

Longitudinal slope Optimal longitudinal slope is approximately 2% at bottom of the swale. Low slopes reduce public hazards and limit erosion by reducing water velocities and increase pollutant removal by increasing residence time.

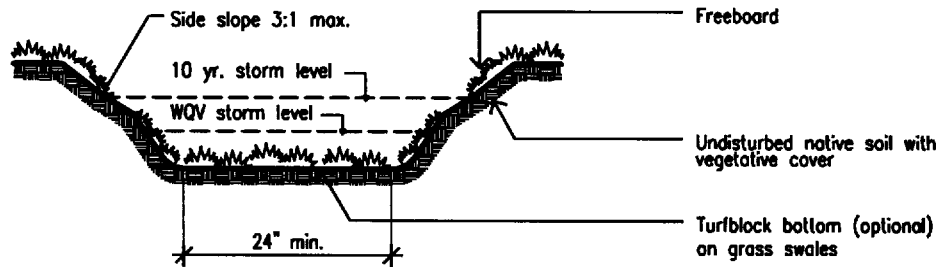
For slopes $\leq 1\%$, install an underdrain to limit standing water in swale.

Install check dams approximately every 50 to 100 feet on slopes between 4% and 6% to reduce velocity.

Do not use swales on slopes greater than 6%.

Installing turf block bottoms on grass swales can minimize wet, muddy con-

Grass/vegetated swales, continued



Typical Section

Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

ditions that hinder maintenance activities.

Side slope 3:1 (horizontal:vertical) or shallower, to limit erosion and to improve maintainability.

Residence time 9 minutes achieves approximately 80% removal of total suspended solids (TSS).

Inlet Sheet flow or multiple dispersed inlets are better than a single inlet.

If a single inlet (pipe or curb cut) is necessary, design an energy dissipator and flow spreader (such as cobbles or gravel) where water enters the swale to reduce erosion and maintenance.

Planting Select plant species that can survive through both periods of inundation and periods of drought.

A variety of grass species, including native and non-native, can together produce a swale turf that is adapted to varying site environments (see table).

Both trees and shrubs can be located adjacent to swales, and on the banks of larger swales.

If planted with turfgrass, provide supplemental irrigation, to keep swale green year round.

Establishment If establishing vegetation during the dry season, it must be planted at least one month prior to the beginning of the rainy season and irrigated to promote establishment until regular rains begin.

If establishing vegetation during the wet season, divert stormwater runoff from the swale during the first rainy season in which the vegetation is being established.

Erosion control measures such as netting or blankets may be used to aid establishment.

Mosquito prevention Design for maxi-

mum residence time of 24 hours (mosquitoes generally require 48 hours to breed and hatch).

Maintenance

- Grass swale maintenance includes mowing and removing clippings and litter; vegetated swales may require additional maintenance of plants.
- Periodically remove sediment accumulation at top of bank, in swale bed, or behind check dams.
- Monitor for erosion and reseed grass or replace plants, erosion control netting and mulch as necessary.
- Fertilize and replace turf well in advance of rainy season to minimize water quality degradation.

Economics

- Grass swale construction cost per linear foot \$4.50-\$8.50 (from seed) to \$15-20 (from sod), compare to \$2 per inch of diameter underground pipe

e.g., a 12” pipe would cost \$24 per linear foot).

- \$0.75 annual maintenance cost per linear foot

Examples/resources

- 10.9 acre site drains parking lot and roof runoff into swales. BT Office Supply Warehouse, 6601 Overlake Place, Newark, CA.
- Parking lot and roof runoff drains to swale at office building. 3150 Porter Drive, Palo Alto, CA.
- Santa Clara Valley Water District offices. 5750 Almaden Blvd., San José, CA.
- Landscape Architecture Technical Information Series (LATIS), *Vegetated Swales*, 1999.

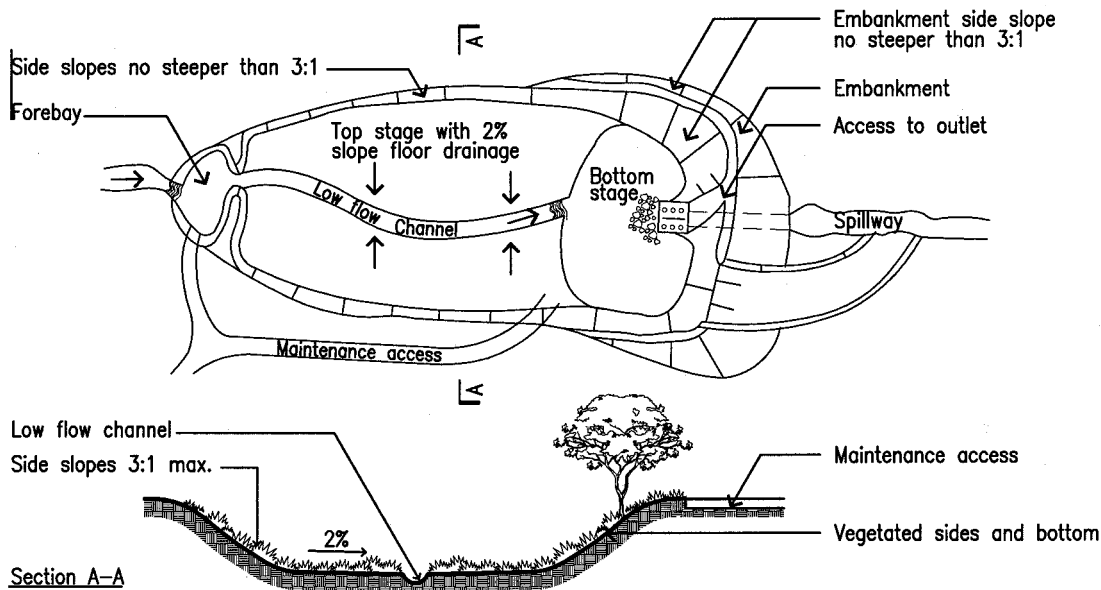
Grass species for swales

There are many alternatives to conventional turfgrass suitable for use in vegetated swales.

Scientific Name	<i>Festuca rubra</i> †
Common Name	Molate/Red fescue
<i>Agrostis exarata</i> †	<i>Hordeum brachyantherum</i> †
Bentgrass	Meadow barley
<i>Bromus carinatus</i> †	<i>Hordeum brachyantherum salt</i> †
California Brome	Meadow barley salt
<i>Buchloe dactyloides</i>	<i>Juncus spp.</i>
Buffalo Grass	Rushes
<i>Elymus triticoides</i>	<i>Stipa pulchra</i> †
Creeping wildrye	Purple needle grass
<i>Festuca idahoensis</i>	<i>Vulpia myuros v. hirsuta</i> †
Idaho fescue, Blue bunchgrass	Zorro annual fescue

† *California native*

Extended detention (dry) ponds



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Extended detention (dry) ponds store water during storms for a short period of time (from a few hours up to a few days), and discharge water to adjacent surface waters. They are *dry* between storms, and do *not* have a permanent pool of water.

Characteristics

- If properly designed, ponds can have a lifetime of 50 years.
- Clay or impervious soils should not affect pollutant removal effectiveness, as the main removal mechanism is settling.
- Pollutants removed primarily through gravitational settling of suspended solids, though a small portion of the dissolved pollutant load may be removed by contact with the pond bottom sediments and/or vegetation, and through infiltration.
- Moderate to high removal of suspended solids (sediment) and heavy metals.

- Low to moderate removal of nutrients and Biological Oxygen Demand (B.O.D.).
- Pollutant removal can be maximized by increasing residence time (average 24 hours); two-stage pond design, with the addition of wetland vegetation to lower stages of the pond; sediment-trapping forebay to allow efficient maintenance; regular maintenance and sediment cleanout; installing adjustable gate valves to achieve target detention times; designing pond outlet to detain smaller treatment volumes (less than two-year storm event).

Applications

- May be initially used as construction settling basins, but must be regraded and cleaned out before used as a post-construction wet pond.
- May be designed for both pollutant removal and flood control.
- May be appropriate for developments of 10 acres or larger.

- Potential for multiple uses including flood control basins; parks, playing fields, and tennis courts; open space; overflow parking lots.

Design

- Coordinate pond design, location, and use with local municipal public works department and/or county flood control department to reduce potential downstream flooding.
- Default conditions for safety have been to fence basins with chain link. Consider aesthetic design elements with safety analyst to address pond barriers, such as fencing and/or vegetation, and shallow side slopes (8:1 to 12:1).

Residence time Design pond for an average residence time of 24 hours, with a maximum of 40 hours.

Slopes Inside basin slopes should be not greater than 3:1 (horizontal:vertical), to minimize erosion and allow heavy equipment access for periodic cleanout.

Inlet Design energy dissipation at the inlet to minimize erosion and promote settling in the forebay. A trash rack can be installed at the inlet to capture large debris before it enters the basin.

Outlet Vertical risers, negatively sloped pipes, and perforated pipes in a gravel bed are all methods of discharging water from the pond. Vertical risers have the advantage of being less susceptible to clogging.

Vegetation Vegetation can enhance pollutant removal and the aesthetic appearance of extended detention ponds. Specify emergent wetland vegetation and non-wetland plants tolerant of inundation.

Mosquito prevention Minimize pond area that has a depth less than 18 inches.

Use foundation aeration to limit periods of still water during detention.

Plant emergent vegetation with minimal submerged growth.

Apply *Bacillus* (Bti) or other bacteria.

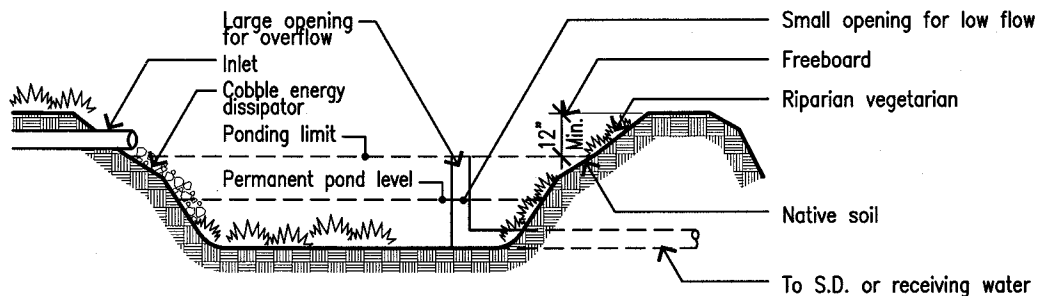
Maintenance

- Regular inspection during wet season for sediment buildup and clogging of inlets and outlets (designing forebay to trap sediments can decrease frequency of required maintenance, as maintenance energy is concentrated towards a smaller area of the basin, and less disruptive than complete cleaning).
- Clean inlet trash rack and outlet standpipe as necessary.
- Clean out basin sediment approximately once per year (this may vary depending on pond depth and design, and if forebay is used). Once site is stabilized, annual cleaning will not likely be needed.
- Mow and maintain pond vegetation, replant or reseed as necessary to control erosion.

Economics

- Least expensive stormwater quality pond option available. 0-25% additional cost when added to conventional stormwater detention facilities.
- Construction cost \$0.10-\$5.00 per cubic foot of storage (savings from preparing silt basins used during construction for use as extended detention ponds).
- Maintenance cost 3-5% of construction cost annually.

Wet ponds



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Wet ponds are permanent pools of water that detain and treat stormwater runoff. They can be enhanced by designing a forebay to trap incoming debris and sediment, and by establishing a fringe wetland at the pond edge to increase pollutant removal and enhance the aesthetic, economic, and habitat value of the pond.

Characteristics

- If properly designed, wet ponds can last indefinitely.
- Clay or impervious soils should not affect pollutant removal effectiveness, as the main removal mechanism is settling.
- Can increase property values by providing a significant landscape amenity.
- Wet ponds provide moderate to high removal of most urban stormwater pollutants, including total suspended solids, sediment, heavy metals, phosphorus, nitrogen, and B.O.D. Removal rates are dependent on residence time

of water in pond, amount of wetland vegetation fringing the pond, and other factors.

- Pollutants are removed by settling suspended solids, uptake by wetland plants and algae, and bacterial decomposition.

Applications

- Wet ponds are appropriate for stormwater drainage in a development or project with a drainage area greater than approximately 2 acres, but are more cost effective for drainage areas greater than 10 acres.
- Landscape amenity in residential or commercial development with opportunities for passive recreation (e.g., birdwatching, fishing, boating), and can be combined with consideration to pedestrian and bicycle circulation to provide active recreation.
- May be initially used as construction settling basins, but must be regraded and cleaned out before used as a post-construction wet pond.

Design

- Coordinate pond design, location, and use with local municipal public works department and/or county flood control department to reduce potential downstream flooding.
- Pretreatment may be needed to remove trash, debris and sediments and to reduce maintenance.
- For risk management, basins area often fenced. Other alternatives to minimize risk include screening vegetation and shallow side slopes (8:1 to 12:1).

Area Surface area must equal 1% of the drainage area for high pollutant removal (e.g. 100 acre drainage area would require a 1 acre wet pond).

Storage volume Design permanent pool to store 0.5-1.0" of runoff per contributing watershed area (a storage volume of 1.0" of runoff per contributing watershed area in the Bay Area will capture and treat the runoff from about 75-85% of the rainstorms each year).

Residence time In general, pollutant removal increases as residence time increases. Pollutant removal can be accomplished with a few days of residence time. The California Stormwater BMP Handbook: Municipal recommends that removal of very fine sediments and removal of dissolved nutrients by plants requires a minimum residence time of 14 days.

Side slopes Forebay side slopes 4:1 to allow access for heavy equipment for periodic cleanout and sediment removal.

Permanent pool side slope 4:1 or shallower if wetland vegetation will be planted around the edge. Shallower slopes will also increase safety and wildlife habitat value.

Depth Range from 3 to 9 feet maximum. A depth greater than 9 feet may produce odor generated from depletion of oxygen in bottom sediments.

Length to width ratio Minimum 3:1 length:width ratio, baffles separating inflow and outflow pipes, and small islands will help avoid flow short circuiting.

Inlet and Outlet Energy dissipation should be used to minimize erosion and promote settling in the forebay.

A weir overflow should be used to pass high-return period (50- or 100- year) flows through the pond and to avoid erosion and flooding.

Vegetation Wet ponds may be constructed with or without a fringe wetland. If fringe wetland is not used, inundation-tolerant grass or other vegetation may be used on the banks. However, this will lower pollutant removal and wildlife value. Wet pond vegetation should consist of wetland plants, including emergent plants, and non-wetland plants tolerant of inundation.

Where fringe wetlands are used, wetland vegetation should occupy 25-50% of the pond surface area to enhance pollutant removal.

Establish vegetation with irrigation 6 months prior to the rainy season, to stabilize the wet pond prior to the rainy season. If this is impossible, appropriate erosion control measures such as blankets, matting, or mulch may be used.

Maintenance

- Check facility annually and after each major storm for erosion and debris.
- Approximately every 2-5 years (when 10-15% of storage volume has been lost), remove sediment from forebay and main pool. Studies generally indicate that pond sediments meet sludge toxicity limits and can be safely disposed of as normal landfill.
- Replant or reseed as necessary to control erosion.
- Provide supplemental water in summer, if required.

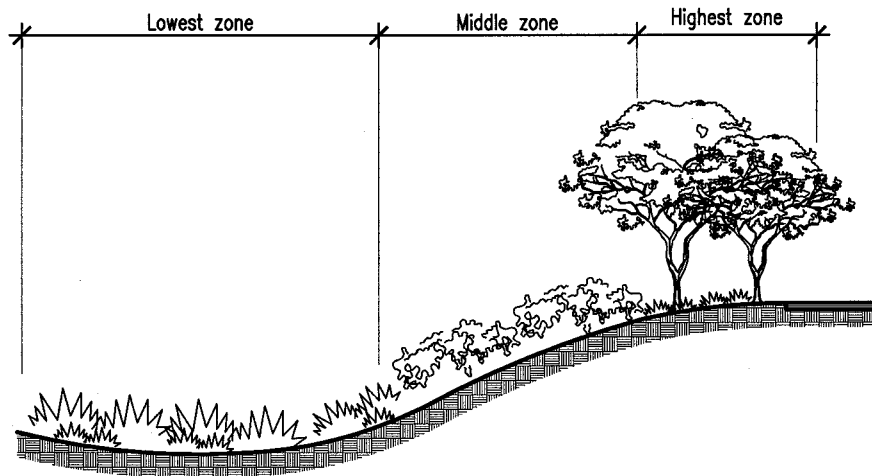
Economics

- Construction cost: \$0.50-\$1.00 per cubic foot of storage.
- Annual maintenance cost is approximately 5% of capital cost for <100,000 cubic feet of storage; 3% for 100,000-1,000,000 cu. ft.; 1% for >1,000,000 cu. ft.

Examples/resources

- Ponds planned to receive summer dry weather flows from landscape irrigation and car washing uses in residential development. Basking Ridge, San José CA.
- West Davis Ponds, Davis, CA.
- Parking lot and structure runoff drain to wet pond in strip mall development. South Napa Marketplace, Napa CA.

Plant species selection for infiltration areas



Conditions, dimensions, and materials shown are typical. Modifications may be required for proper application, consult qualified professional.

Plant species selection for infiltration areas can improve the infiltration potential of landscape areas as well as improve the aesthetics of design.

Characteristics

- Deep rooted plants help to build soil porosity.
- Leaf surface-area helps collect rainwater before it lands on the soil, especially in light rains, increasing the overall water holding potential of the landscape.
- Select species that are tolerant of moist soils or periodic inundation, as well as drought if planted without supplemental irrigation.

Applications

- Applicable to all treatment devices that incorporate plant materials.

Design

- Select appropriate plant species depending on zone of inundation: lowest, middle, and highest.
- Most plants and grasses require initial irrigation during establishment period,

as well as during dry periods.

- Select the appropriate plant for the use, water cycle, and aesthetic goals.
- Consider sight-line and other requirements for parking lots and street-side plantings.
- Include mulch cover in planting areas.

Maintenance

- Maintenance can have a significant impact on soil permeability and its ability to support plant growth. 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, where the majority of small absorbing roots lie. 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.

- Slightly more attention to maintenance and care of plant material may be required than in non-infiltration areas.

Economics

- Riparian and native plant material species are approximately 20% more expensive to purchase than common landscape species.
- Changing from the leaf blower maintenance practice to more manual practices may increase labor cost.

Plant Species for Infiltration Areas

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

Highest Zone

<i>Acer negundo</i>	Box Elder
<i>Acer rubrum</i>	Red Maple
<i>Acer saccharinum</i>	Silver Maple
<i>Alnus spp.</i>	Alder
<i>Betula spp.</i>	Birch
<i>Carya illinoensis</i>	Pecan
<i>Carya ovata</i>	Buttonbush
<i>Casuarina spp.</i>	She-Oak
<i>Clethra arborea</i>	Lily-of-the-Valley
<i>Cornus stolonifera</i>	Redtwig Dogwood
<i>Diospyros virginiana</i>	Persimmon
<i>Eucalyptus camaldensis</i>	Red Gum
<i>E. citriodora</i>	Lemon Gum
<i>E. erythrocorys</i>	Red-Cap Gum
<i>Fraxinus latifolia</i>	Oregon Ash
<i>Gleditsia triacanthos</i>	Honey Locust
<i>Liquidambar styraciflua</i>	Liquidambar
<i>Liriodendron tulipifera</i>	Tulip Tree
<i>Magnolia grandiflora</i>	Southern Magnolia
<i>M. virginiana</i>	Sweet Bay
<i>Melaleuca quinquenervia</i>	Cajeput Tree
<i>Nyssa sylvatica</i>	Tupelo
<i>Picea sitchensis</i>	Sitka Spruce
<i>Platanus x acerifolia</i>	London plane
<i>Platanus occidentalis</i>	Sycamore
<i>P. racemosa</i>	California Sycamore
<i>Populus deltoides</i>	Cottonwood
<i>Pterocarya stenocarpus</i>	Wingnut
<i>Quercus macrocarpa</i>	Bur Oak
<i>Q. palustris</i>	Pin Oak

<i>Salix spp.</i>	Willow
<i>Sequoia sempervirens</i>	Coast Redwood
<i>Taxodium distichum</i>	Bald Cypress
<i>Thuja occidentalis</i>	Arborvitae

Middle Zone

<i>Cornus stolonifera</i>	Redtwig Dogwood
<i>Gaultheria shallon</i>	Salal
<i>Equisetum hyemale</i>	Horsetail
<i>Ferns (many spp.)</i>	Fern
<i>Iris (many spp.)</i>	Iris
<i>Mimulus</i>	Monkeyflower
<i>Miscanthus sinensis</i>	Japanese Silver Grass
<i>Myoporum parvifolium</i>	Myoporum
'Putah Creek'	
<i>Myrica</i>	Pacific Wax Flower
<i>Salix spp.</i>	Willow
<i>Vaccinium</i>	Huckleberry

Lowest Zone

<i>Acorus gramineus</i>	Acorus
<i>Carex spp.</i>	Sedge
<i>Deschampsia caespitosa</i>	Tufted Hairgrass
<i>Iris (many spp.)</i>	Iris
<i>Leucothoe davisiae</i>	Sierra Laurel
<i>Scirpus cernuus</i>	Bulrush
<i>Juncus spp.</i>	Rush
<i>Tradescantia virginiana</i>	Spiderwort
<i>Typha latifolia</i>	Common Cattail

Table adapted from Harris (1992), *Sunset Western Garden Book* (1988), and *ABAG* (1995b)