APPENDIX F

REVIEW OF COUNTY DESIGN
STANDARDS, LID/ BMP
SPECIFICATIONS/STANDARDS
Schaaf & Wheeler has reviewed the County of Santa Cruz (County) stormwater management design criteria as set forth in Part 3 of the County of Santa Cruz Design Criteria Manual (June 2006). Part 3 of the County Design Criteria (CDC) is reviewed on the basis of technical merit (age, adequacy, and accuracy of background data, technical methodology, etc), ease of use, consistency with existing and expected requirements, and consistency with other municipal criteria, adequacy and effectiveness. In addition to the stormwater management section of the County design standards, Schaaf & Wheeler has reviewed those sections of the street design (Part 2) and driveways (Part 6) which relate directly to stormwater runoff. Existing County impervious area mitigation requirements, which do not have a stand alone section in the CDC but are generally covered within the Stormwater Management retention/detention sections, are also reviewed. This memo outlines the findings of this review.

This memorandum was submitted to the County in Draft format in March, 2011 and finalized based on comments received from the County in April, 2012. Concurrent with Schaaf & Wheeler’s finalization of this memorandum, the County updated their design standards in March, 2012, incorporating many of the recommendations made by Schaaf & Wheeler herein. Similarly, the County updated its Stormwater Management Plan after development of the Draft of this memorandum, rendering some of the comments herein pertaining to the Stormwater Management Plan out of date. The County transmitted additional comments to Schaaf & Wheeler in April, 2013, and this memorandum has been revised to address those comments.

The review is broken into eight sections: Hydrology (CDC Section 3C), Hydraulics (CDC Section 3D), Storm Drainage Facilities (CDC Section 3E), Detention (CDC Section 3G), Retention (CDC Section 3H), Streets (CDC Part 2), Driveways (CDC Part 6), and Impervious Area Mitigation. This document notes aspects of the Design Criteria that are unique to the County (compared to other municipal criteria) and provides recommendations for sections of the County Design Criteria to be updated in future revisions. In general, stormwater criteria and
methodology found in the County Design Criteria that is standard and acceptable is not specifically noted in this document. This document is not intended to serve as an update to the County Design Criteria.

**Hydrology (County Design Criteria, Section 3C)**

Most of the hydrology section is generally congruent with requirements in neighboring municipalities.

The County Design Criteria (CDC) provide rainfall intensity data via Figures SWM-2 and -3 (isopleths and IDF curves). The data is known to be approximately 30 years old. In recent years, County staff has conducted analyses which indicate that utilizing updated rainfall statistics does not create significant changes to the resulting figures. Schaaf & Wheeler has not completed an independent review of these analyses.

Schaaf & Wheeler recommends that future updates to the CDC include revisions to the time of concentration calculation methodology. The design standards provide a nomograph for calculation which only applies to natural watersheds. Since land use throughout the county is varied, guidance for the calculation of time of concentration for various land uses should be provided. Many municipalities provide an equation, instead of or in addition to nomographs, to allow for variables to be altered as deemed appropriate for specific watersheds or varying land uses. Example methods commonly used in other municipalities include the Kirpich formula (for natural or rural land uses), or for application in urban or rural watersheds, a specified roof-to-gutter time (usually between 5-15 minutes) added to a calculated overland time of concentration based flow length and average velocity. Nomographs may be provided for average velocities for various slopes/land uses.

A variety of hydrologic methodologies are allowed for watersheds greater than 200 acres. Though a 25% safety factor is prescribed (to account for variance between methods), most municipalities prefer proscribing a specific method (commonly SCS for large basins) to provide uniformity, confidence in calculation, and ease in review.

**Hydraulics (County Design Criteria, Section 3D)**

Overall, the requirements found in the Hydraulics section are fairly typical of municipal design standards with a few exceptions.

The CDC state that in providing for design flood overflow protection, roadway overflow is not permitted (with some exceptions). The 'design flood' is defined in the Hydrology section 3C1, and ranges from the 25-year event to the 100-year event, based on site size. This requirement seems to suggest that during storm events greater than the design flood, flows in the roadway are not permitted, which is an unusual and likely infeasible standard which also conflicts with later standards regarding gutter flow. Based on feedback from County staff, we understand that this language may be meant to refer to the overtopping of streets at stream culverts, which is more
standard, however we recommend that the language be revised to clarify the allowable overflow from the storm drain system in streets / culverts / streams. Many municipalities encourage flow in excess of the 10-year event to be carried within street right-of-way with the exception of major emergency access roads, where a minimum travel lane width is specified. This standard is generally feasible to accomplish while still preventing structure damage. The CDC requires finished floor elevations to be set one foot above the design flood level. It is typical for municipalities to require finished floor elevations for properties inside of special flood hazard area, as defined on a Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) be set at least one foot above the FEMA 100-year base flood elevation, regardless of site size.

Many of the detailed calculation methodologies and assumptions are 'buried' within exhibits SWM-6 and SWM-7. For ease of use, Schaaf & Wheeler recommends these standards, methodologies, and assumptions be explicitly stated within the text of the document in addition (or alternatively to) the exhibits. SWM-7 provides direction for calculations to be completed "for pipe flowing full" and "if flow is subcritical", however there is no direction for methodology to be applied if these conditions are not the case, nor does the figure direct designers whether these are required assumptions. In general, other municipalities require hydraulic calculations to determine if a pipe being analyzed is in fact flowing full and in sub or super critical flow conditions, and the appropriate application of various loss equations based on that finding. If the downstream limit of an analysis is a continuing storm drain system (as opposed to an outlet), then a full pipe at that downstream limit is a common assumption.

No Manning’s ‘n’ values are provided for natural channels or ditches. While the reference documents referred to in the CDC do include this information, it may be helpful to include design values for different types of rock-lined, blanket-lined, or vegetative-lined channels, as well as specific values (instead of the range provided) for different types of plastic pipe (PVC, ABS, HDPE) and cast iron pipes within the CDC. Recommended values can be found in water resource manuals, including the McGraw-Hill series in *Water Resources and Environmental Engineering* (1979) or *Open-Channel Hydraulics* by Ven te Chow (1959).

Open channels are forbidden within residential areas, a restriction which is not typical and not found in other municipalities. This limitation restricts the use of many LID/BMP stormwater treatment options. Unless this restriction is meant to refer only to high density residential, this is not typical or even recommended in other municipalities.

**Storm Drainage Facilities (County Design Criteria, Section 3E)**

Overall, the requirements found in the Storm Drainage Facilities section are typical. One exception is that the manual requires a bridge structure when flows necessitate a culvert greater than 6 feet in diameter, effectively limiting culvert sizes in the County to 6 feet. Other municipality's manuals reviewed for this analysis do not specify a maximum culvert size.

The second exception is the standards regarding 'Water Quality Treatment Units', which the CDC state may be required at manholes or storm drain inlets. Figures SWM 11 and 12 show
example water quality treatment units, which effectively create a standing volume of water which then seeps into the surrounding ground. The figures call for impermeable materials to be used for projects that have the potential to cause groundwater contamination; Schaaf & Wheeler recommends that such units not be allowed at all for projects which may cause groundwater contamination. A minimum emptying time of 72 hours for units should also be specified for consistency with typical vector control measures.

**Detention (County Design Criteria, Section 3G)**

The County endeavors to keep 'policy' direction out of the CDC document, instead including policy information (such as downstream impacts analysis and detention criteria requirements) in the Santa Cruz County General Plan. This is atypical, and most municipalities include this information directly in their design criteria (as well as their General Plans). While the CDC does reference the relevant General Plan sections, it is recommended that the County explicitly state that criteria (or 'policy') for onsite stormwater detention requirements may be found in those sections.

The County General Plan (7.23.1) states that new development must "provide both on and off site improvements to alleviate flooding problems before consideration of on-site detention of stormwater" as well as "require runoff levels be maintained at predevelopment rates for a minimum design storm...to reduce downstream flood hazards and analyze potential flood overflow problems, where applicable."

Regarding on-site stormwater detention, the General Plan states (7.23.3) that "where it is not possible to alleviate drainage problems through on and off-site improvements...require on-site stormwater detention sufficient to maintain, at a minimum, post-development peak flows at pre-development levels for the selected design rainstorm for all development projects greater than one acres in area, and to alleviate current drainage problems, if feasible." Based on these statements, our understanding is that the goal of on-site detention is to address flooding concerns, not for water quality treatment, which is addressed via the retention requirements, discussed below.

The phrasing of these sections of the General Plan is confusing. Based on comments from City staff, there is inconsistency in when detention is required (comments received from different reviewers use different criteria - parcels exceeding one acre vs. 500 square feet of new impervious surfaces, for example). Based on communication with County staff, Schaaf & Wheeler understands the practiced standard is that all new development is required to hold runoff levels to predevelopment rates for the 10-year event; however section 7.23.3 seems to suggest that for projects greater than one acre; if drainage problems can be alleviated through off-site improvements, on-site detention may not be required. It is our understanding that this is not the intent of the section, and rather it is to discourage detention on projects less than one acre in size. Schaaf & Wheeler recommends the language in the General Plan be clarified in future General Plan updates, and that specific criteria for when detention is required be developed.
Neither the "minimum design storm" referenced in section 7.23.1 nor the "selected design rainstorm" referenced in Section 7.23.3 are clearly defined in the CDC. The CDC states that the "minimum criteria for providing on-site detention is that the maximum rate of runoff leaving the developed site shall not exceed the runoff rate from the pre-development site based on a 10-year storm, 15-minute time of concentration, including a 25% safety factor.". Based on this statement, we conclude that the standard 'peak matching' required by the CDC and General Plan is that the post-project 10-year peak runoff rate must not exceed the pre-project 10-year peak runoff rate, regardless of development size, or on or off site system capacities or improvements. We recommend that the phrasing used in the general plan to explicitly define the "minimum design storm" and the "selected design rainstorm", particularly if the interpretation stated above is incorrect.

The minimum criteria, as quoted above, calls for detention to be required based on a 10-year storm and 15-minute time of concentration (Tc). Schaaf & Wheeler recommends removing the reference to 15-minute Tc, and instead requiring detention to be based on actual calculated time of concentration for existing and post project conditions. A smaller Tc leads to a higher peak runoff. Therefore, particularly for large, undeveloped sites, specifying a Tc of 15 minutes, when the actual existing Tc may be much larger, could lead to over-estimating the existing peak runoff, thereby under-designing the detention required to actually mitigate impacts to the 10-year peak runoff. Schaaf & Wheeler notes that the intention of this criteria as written may be to specify that regardless of calculated Tc, a minimum Tc of 15-minutes should be applied. If this is the case, Schaaf & Wheeler recommends that the language be modified to clarify this and clearly convey that the actual time of concentration should be calculated, with a minimum Tc of 15-minutes applied to detention design.

The requirement that post project runoff be mitigated to pre-project peak rates is standard and typical of other municipalities, although the exact 'peak matching' event varies considerably across municipalities. For flood control purposes, some municipalities require detention of the difference between the 10-year and 100-year peaks while others require detention only to mitigate the impact of the 100-year storm. Virtually all other municipalities require some mitigation of increases to the 100-year peak runoff rate. The General Plan states (7.23.1) that new projects are required "to provide both on and off-site improvements to alleviate drainage problems before considering on-site detention of storm water". This suggests that off-site improvements must be provided in addition to mitigation of peak runoff, which is not typical. Generally, if off-site drainage improvements are to be made it is treated as a mitigation measure for an increase in peak site runoff. If our review has misinterpreted the intent of this policy, we recommend that it be revised to more clearly define when off-site improvements are required. Schaaf & Wheeler recommends that site developers be given the option to show how they will achieve no drainage impacts (which may be achieved via off-site improvement or on-site detention). Additionally, the use of the word "considering" is vague, and does not clearly convey under what conditions a project can (or must) include on site detention.

Utilizing the modified rational method for detention design is typical. The drainage standards state that detention should be designed for “a broad range of storms”. While it is typical for detention to be designed for a range of storms, generally, municipalities are very specific as to the upper and lower limits of the range of storms that must be detained. As described above,
interpretation of the CDC is that the minimum upper bound that detention must be designed for is to mitigate for increases to the 10-year storm event, a typical and feasible requirement.

In the design standards, there are several available nomographs for calculating the required detention volume for a variety of storms yet there is little guidance as to when each should be used. Based on communication with County staff, we understand that more stringent detention requirements/nomographs may be required in areas of the County that are known to be particularly impacted by increased peak runoff. Schaaf & Wheeler recommends that a map or other guidance be provided to clarify where and when the various nomographs should be applied.

The time of concentration methodology in this section is problematic. Time of concentration is very site specific, based on size and shape of watershed, soil type, land use, topography, etc. The manual requires a pre-development time of concentration of 15 minutes and the detention basin size calculation nomograph is based on that. This is a time of concentration more typical of a fully developed, small watershed. Detention basins sized with this method may be under-sized.

Finally, the design standards require that for underground structural detention systems, the predevelopment flows bypass the detention facility so that the storage volume is used only for the additional runoff generated by the new development. Based on feedback from County staff, we understand that the intent and practice of this requirement is to allow predevelopment flows to be diverted at the inlet to the facility, or, where sediment loading is not a concern, to pass through the facility and outlet works, not utilizing any of the storage volume. This phrasing is confusing, and suggests that predevelopment flows must bypass the facility entirely (i.e. be directed away from the facility via site grading or design instead of being diverted or bypassed within the facility itself); a requirement that is atypical, difficult to construct, and not the intended criteria. Schaaf & Wheeler recommends that this criterion be eliminated from the CDC.

**Retention (County Design Criteria, Section 3H)**

Similar to detention, the requirements for which developments must include retention are stated in the General Plan, not the CDC. This is atypical, and as such, we recommend that the County explicitly state that the information (or 'policy') regarding when projects are required to provide retention is located in the General Plan. The General Plan states that on-site retention of increased runoff is required in Water Supply Watersheds and Primary Groundwater Recharge Areas (as well as other areas as feasible). We recommend this statement in the General Plan include a reference to the CDC. Based on where retention in the County is required (Water Supply Watersheds and Primary Groundwater Recharge Areas) we assume that the primary purpose of retention in the County is to achieve water quality treatment and/or groundwater supply related goals, not flood control mitigation. This review applies that assumption throughout. Schaaf & Wheeler recommends that a map showing Water Supply Watersheds and Primary Groundwater Recharge areas be added either to the General Plan or CDC.

Overall, the requirements found in the Retention section are unique to the County of Santa Cruz. The design standards allow two methods for the design of retention: the Slope Infiltration
Method and the Storage Percolation Method. Though the Storage Percolation Method is typical (in general, though not as set forth in the design standards), there are no other municipalities that we are aware of that allow the Slope Infiltration Method. With the difficulty of implementation of retention in moderate/steep sloped development areas, this method provides an option where otherwise the County may have to declare a project exempt due to over-constrained project conditions. Based on comments from County staff, we understand that the criteria regarding the Slope Infiltration Method have been developed with consultation from geotechnical and civil engineers.

It is common for volume based water quality treatment methods to be designed for a 'treatment volume'. For the Storage Percolation Method, the design standards require retention of the 2-year 2-hour storm, which serves as the 'treatment volume' for retention requirements, although that specific phrase is not used in the CDC. Depending on location within the County, this equates to a 0.6 - 1.5 inch rainfall event. Most municipalities have adopted one of the two methods recommended by the California BMP Handbook: Either the maximum stormwater quality capture volume for the area based on historical rainfall records and formula and volume capture coefficients set forth in *Urban Runoff Quality Management WEF Manual of Practice No. 23 and ASCE Manual of Practice No. 87 (1998)* or the volume of annual runoff required to achieve eighty percent or more capture, determined in accordance with the methodology found in the California BMP Handbook. It should be noted that in the County Stormwater Management Plan (2009) reviewed for this effort, the County states its intention to adopt the methodologies outlined in Attachment 4 of the General Permit, which in turn references the California BMP handbook methodology for volume based water quality treatment design. Schaaf & Wheeler recommends that the CDC be updated to clarify the purpose of required retention, and to be consistent with the County Stormwater Management Plan regarding water treatment volume calculation methodology. Note that the Regional Water Quality Control Board has issued a Draft Phase II General Permit which, when adopted, will supersede the General Permit Attachment 4 requirements. The Draft Phase II General Permit defines the water treatment volume as the runoff produced from the 85th percentile storm.

The CDC requires an iterative process such that rainfall onto the retention area is accounted for in the sizing criteria. If the primary goal of the retention is groundwater recharge, this is logical. However; if the primary goal is water quality treatment, then there is no need to treat rainfall that has not runoff from an impervious surface, and thus this iterative process is needlessly complex. The primary goal of retention requirements is unclear.

It should be noted, however, that current trends in hydromodification mitigation required by nearby regional RWQCBs requires analysis and demonstrated mitigation of impacts to runoff duration and frequency for events up to the 10-year storm event. The Draft Statewide Phase II Permit hydromodification criteria requires, for the Coast Range area, that post-project runoff not exceed pre-project volume and rate for the 2-year, 24-hour storm. As such, it is unlikely that the existing retention criteria, as written, will meet anticipated RWQCB hydromodification mitigation requirements.
The CDC does not provide a lower bound for the range of storm that must be mitigated for. As such, currently the CDC does not mitigate for increases to runoff from more common storm events (although retention, discussed later, may provide some mitigation in areas where it is required). For comparison, in the San Francisco Bay area for HMP (hydromodification) purposes, the basis for detention design is 10% of the 2-yr (lower bound) through the 10-year. Other municipalities use 50% or the full 2-year, instead of 10% as the lower bound. As hydromodification mitigation becomes more prevalent in Central Coast NPDES permitting, runoff frequency, duration, and volume instead of peaks are often being considered in establishing these bounds. The bounds should be chosen based on the needs of the County, the condition of streams, creek capacity, and local NPDES and regional water board requirements.

Retention sizing methodologies in the design standards state that requirements are based on new impervious surfaces. The majority of regional water quality control board (RWQCB) requirements are based on both new and re-developed impervious surfaces. Based on comments from County staff, our understanding is that in practice, all impervious surfaces (new and existing) are subject to the detention requirements unless the applicant can prove that the existing impervious surfaces predate the creation of the flood zone district in which the project is located. If the County intends to continue applying this requirement, it should be included in the CDC and/or General Plan (along with delineation and dates of creation of the flood zones).

Other detention requirements regarding screening and structural requirements are not unusual, though most manuals do not provide such specifics.

The threshold for requiring retention is also unique. The design standards state that projects creating less than 500 square feet of new impervious surfaces are exempt from specific quantitative retention requirements. Most municipalities, and recent NPDES permits, do not require quantitative retention analysis unless the project is creating or replacing 5,000 - 10,000 square feet (depending on land use type) of impervious surface. Retention for hydromodification or flood control purposes is generally not required unless 1 acre of impervious surface is being produced. The County's current Stormwater Management Plan (May, 2009), uses 5,000 square feet of new/replaced impervious surface for the hydromodification 'trigger'. Most new development within the County's jurisdiction are small projects that are well below these larger, more common thresholds. Thus, in order to encourage retention for water quality or supply goals, this lower threshold is appropriate, however the County may with to consider updating this criteria to be consistent with the Draft Regional Water Quality Control Board NPDES permit and the County's Stormwater Management Program.

**Streets (County Design Criteria, Part 2)**

Schaaf & Wheeler reviewed the streets sections that relate directly to stormwater runoff. Specifically, Sections A, C, F, and J.
The requirements found in the Streets section, as relating to stormwater, are adequate and typical. Our understanding is that the County is interested in revising the CDC to incorporate LID/BMP techniques. Several of the specifications should be updated to encourage greater impervious area mitigation and LID techniques. The minimum street widths provided are typical, however also providing maximum street widths to encourage decreased impervious area is recommended. Open channels, a common feature of alternative street sections, are currently prohibited by the CDC in residential areas. Schaaf & Wheeler recommends that this prohibition be removed. Concrete grass pavers are the only pervious-surface mentioned, and are prohibited from County maintained right-of-way. This may discourage the use of concrete grass pavers and other pervious-surface techniques on or adjacent to County roads.

Curbs, gutters, and sidewalks are required for all development projects unless a variance is approved through an exception process. Although from a stormwater management perspective curb and gutter is preferable, this requirement may discourage LID street design, which often utilizes curb-less streets with un-paved walking and/or parking areas. Permeable pavement / pavers are not mentioned in the design standards, with the exception of concrete grass pavers. A more general section specifying the applicability, standards, and limitation of permeable surfaces for road and sidewalk design should be added.

**Low Impact Street Cross Sections**

The current Geometric Street Sections provided in the County Design Criteria (Figure ST-1a) do not include a low impact street standard. If the County wishes to encourage the use of street design as a LID measure, a new figure showing Low Impact street section alternatives should be added to the CDC. Note that these changes may require updates to other sections of the CDC for consistency. Specific modifications to the typical sections may include:

- Specifying the use of pervious materials for sidewalk surfaces.
- Specifying the use of pervious materials for rural / low use street surfaces.
- Where sufficient right of way exists:
  - If a low pedestrian use area, include sidewalk on only one side of street, install vegetated drainage swale on other side. Slope entire roadway to drain towards swale. Install cuts in curb to allow roadway runoff to enter swale. Swale should include overflow into local stormdrain system. Guardrail may be required.
  - If sidewalk is required on both sides of street:
    - Shift sidewalks to limit of right of way and convert landscape strip between sidewalk and curb to vegetated swale. Install cuts in curb to allow roadway runoff to enter swale. Swale should include overflow into local stormdrain system. Guardrail may be required.
    - Alternatively, depending on site constraints, allow use of "Alternate Sidewalk Location" and construct vegetated swale between sidewalk and limit of right of way. Install cuts in curb and pipes under sidewalk to
allow roadway runoff to enter swale. Swale should include overflow into local stormdrain system. Guardrail may be required.

- Decrease minimum street widths, and/or add maximum allowable street widths. Where on-street parking is not a high priority, further narrowing of street widths may be possible.

**Driveways (County Design Criteria, Part 6)**

The requirements found in the Driveways section, as relating to stormwater, are typical and appropriate. Similar to the Street section, however, changes can be made to increase impervious area mitigation techniques. Concrete grass pavers are only allowed “when warranted by significant environmental conditions”. This restrictive language discourages the use of concrete grass pavers and other permeable surfaces for driveways. Base rock or gravel is also included as an alternative surface to improve infiltration with appropriate limitations and specifications, with the exception that an asphalt or concrete tie-in apron of 15-feet is required. This distance could be reduced to promote decreased impervious surfaces. Specific impervious area mitigation techniques appropriate to be incorporated into the Driveway Design Standards are presented at the end of this technical memo, see the Street and Driveway Impervious Area Mitigation Techniques section.

**Impervious Area Mitigation**

Schaaf & Wheeler is tasked with reviewing the CDC impervious area mitigation specifications that relate directly to stormwater. As stated above, the existing CDC do not contain a standalone section for impervious area mitigation. The County currently does charge a drainage impact fee for new impervious surfaces; Schaaf & Wheeler recommends that the CDC note this fee requirement and provide a resource to where current fee schedules can be found.

Schaaf & Wheeler recommends that future revisions to the CDC include a new section regarding Impervious Area Mitigation. The purpose of this section of this Memorandum is to provide general recommendations for the scope, standards, level of detail, and specifications to be considered by the County in the development of an Impervious Area Mitigation (IAM) section for future revisions to the CDC.

The new section should provide the requirements for the mitigation of new impervious surfaces including site design and the use of post construction BMP/LID measures. The County may opt to include specific BMP/LID design criteria, or may reference readily available resources for BMP/LID design. The IAM section should be consistent with the County’s existing Stormwater Management Program, and updated on a regular basis to reflect Stormwater Management Program updates. Specific criteria for the percentage of new and/or existing impervious surfaces to be treated should be provided. It is likely that the through this revision process, the County
will find that the existing Retention section can be incorporated into the new Impervious Area Mitigation section.

Site design techniques to mitigate impervious surfaces include maximizing the amount of open space, and utilizing permeable materials wherever possible (such as decomposed granite for pathways instead of concrete, green roofs, or permeable pavement, concrete or pavers). Alternative / Low impact street design, described in more detail in the attached LID information sheet (see Appendix A) may be used to decrease total imperviousness compared with traditional street layout.

Currently, the County does not require any application or permit for removing vegetation and paving of an existing lot. As such, limiting impervious areas via site design does not offer long-term assurance that the impervious surface will be limited on a given lot. Regulations that do offer this assurance (via permit requirements, percent lot coverage limits, etc.) should be considered.

In general, techniques to decrease impervious area are flexible and not highly dependant on site-specific conditions, although site design considerations such as budget, land use, and density must be considered and balanced with decreasing impervious surfaces. For those techniques which utilize replacement of impervious surface with pervious surfaces (i.e. pervious pavement) the underlying function of the technique is infiltration into the underlying soil. As such, impervious area reduction techniques that depend on infiltration into underlying soil must consider and assess the underlying infiltration capacity of that soil, and its bearing on the appropriateness of the technique in that location. Additional details specific to impervious area reduction techniques are provided in Appendix A.

When an increase in impervious area is unavoidable, it may be mitigated by on-site infiltration of runoff via post project BMP/LID techniques. It should be noted that for new development, it is unlikely that any BMP/LID technique, or combination of techniques, will achieve full mitigation (i.e. pre-development conditions) of the increase in peak runoff rate due to the development. For this reason, Schaaf & Wheeler recommends that the Detention section of the CDC be maintained as a separate section from the Impervious Area Mitigation section.

An important consideration in the design and construction of infiltration systems is to understand that the primary cause of failure is clogging of the infiltrating soil interface. On development sites where construction will continue over an extended period of time, the final implementation of the infiltration BMP/LID should be completed after the site is fully developed and the entire catchment area is stabilized for control of sediment from construction activity. Any structural infiltration practices should be provided with upstream pre-treatment BMP/LIDs for removal of sediment (i.e. grass buffer strip, vegetated swale, sediment forebay or screen). While an infiltration trench or basin may provide removal of suspended solids, its primary functions will
be removal of very small particulates and soluble pollutants in the soil profile, reduction of the volume and peak rate of runoff to the storm sewer system and local streams, and increasing the volume of recharge to the local water table.

Currently, the County provides guidance for the use of retention basins within the CDC (Section H3, General Site Selection) such as required set backs from septic systems, minimum permeability, etc. The CDC also notes that water treatment units should be made impermeable for sites with a risk of groundwater contamination. Additional criteria the County may want to consider for future CDC revisions include:

- A minimum separation between infiltration device invert and groundwater. If available, seasonal high groundwater levels should be used in this determination. (Schaaf & Wheeler research yielded a minimum of 10 feet as a common criterion).

- A minimum separation between infiltration device invert and Bedrock or impervious soils. (Schaaf & Wheeler research yielded a minimum of 10 feet as a common criterion.)

- A minimum separation between infiltration devices and private and/or municipal wells.

- Limitations on the use of infiltration devices on sites that are constructed of fill.

- Reduction of drainage impact fees with incorporation of impervious surface mitigation.

The use of impervious area mitigation techniques should not preclude a development site from the stormwater management requirements as detailed in the effective County of Santa Cruz Design Criteria.
Bibliography


Santa Cruz County, Planning Department, *General Plan and Local Coastal Program for the County of Santa Cruz, California*. Effective Date 12/19/94.


Appendix A

LID Information Sheets

These Low Impact Design Standards and Best Management Practices have been gathered and modified to suit County of Santa Cruz applications. The source material is provided as footnotes in each BMP/LID summary sheet.
Bioretention Area/Swales

Purpose/Definition
Bioretention areas function as soil and plant-based filtration devices that remove pollutants through a variety of physical, biological, and chemical treatment processes. These facilities normally consist of a grass buffer strip, sand bed, underdrain, ponding area, overflow inlet, organic layer or mulch layer, planting soil, and plants. The runoff’s velocity is reduced by passing over or through the buffer strip and is subsequently distributed evenly along a ponding area. Percolation of stored water in the bioretention area’s planting soil enters the underdrain such that the bioretention area empties within two days.

Application
Bioretention can be utilized in any type of development. It can be implemented as a function landscape design element.

Limitations
Bioretention is not appropriate for slopes greater than 20%, where water tables are within six feet of the ground surface, or where soil is unstable. As a landscape design element, irrigation may be required. Also, the underdrain is susceptible to clogging, particularly if installed prior to construction site soil stabilization.

Maintenance
Bioretention areas shall be inspected monthly for:

- Obstructions and trash.
- Ponded water. If ponded water is observed after 72 hours after a rainfall event and inspection of the underdrain, cleanouts, outfalls, etc do not show evidence of clogging, the surface soils shall be aerated. If this does not remedy the problem, surface soils should be removed and replaced.

Other maintenance considerations include:

- The use of pesticides and quick-release synthetic fertilizers shall be minimized, and the principles of integrated pest management (IPM) followed. Check with the local jurisdiction for any local policies regarding the use of pesticides and fertilizers.
- Soils and plantings must be maintained, including routine pruning, replenishment of mulch, and weeding.
- Erosion at inflow points must be repaired.
Design Specifications

The bioretention footprint area shall be sized based on the contributing impervious area, and the ratio between rainfall inflow to infiltration rate. For example, with 0.2 inches of rainfall per hour inflow versus 5 inches/hour infiltration rate, the bioretention area would be 4% of the contributing impervious surfaces on the project site. The rainfall inflow shall be determined utilizing methodology presented in the most recent California Stormwater BMP Handbook.

Bioretention area’s planting soil shall have a minimum percolation rate of 0.5 inches/hour and a maximum percolation rate of 10 inches/hour. Native soils rarely meet this percolation requirement even with admixtures, so specific planting soil mixtures capable of and certified to percolate at least 0.5-inch/hour should be utilized. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25 percent. The pH of the soil should range between 5.5 and 6.5. The planting soil shall be a 1.5 to 3 perfect organic content, and a maximum 500 ppm concentration of soluble salts. Soil test should be performed for every 500 cubic yards of planting soil, with the exception of pH and organic content tests, which are required only once per bioretention area. If it is believed that native soils may be able to meet these conditions, in-situ testing shall be conducted to verify that the material meets the percolation requirements.

Bioretention areas shall have a vegetation layer with a 3-inch layer of non-pine mulch or grasses provided in areas between plantings. Shrubs and small trees shall be placed to anchor the bioretention area cover. Irrigation shall be provided to maintain plant life in the bioretention area.

Beneath the planting soil, a layer of sand/loam, between 2’ and 4’ deep (depending on plant species), shall be provided to store treated runoff before seepage into native soil or underdrain. Design surface ponding depths should vary, with a maximum depth of 6 inches. Plant species should be suitable to well-drained soil and occasional inundation.

The inlet to the overflow catch basin shall be at least 6-inches above the low point of the bioretention planting area. The bioretention area shall have a minimum surface slope of 1 percent to local low points. Only areas at least 2 inches below the overflow catch basin elevation shall be considered in the surface area of the bioretention basin. An underdrain system shall be provided for the bioretention area except when percolation tests show that the native percolation rate is greater than 0.5 inches per hour and the depth to groundwater is greater than 6 feet from the surface of the bioretention area. Trees and shrubs shall be planted (at a 2:1 or 3:1 shrub:tree ratio) to provide a total of 1,000 plantings per acre.

Set back from structures shall be at least 10’. Side slopes shall not exceed 2:1; safe conveyance of overflow shall be required. Inlets must be protected with rocks, cobbles or splash blocks. Curb cuts shall have 12” minimum width. An overflow path must be designed to safely convey design flood flows to a downstream storm drain or discharge point. If required per these specifications, the underdrain shall provide a clean-out
consisting of a vertical, rigid, non-perforated PVC pipe, with a minimum diameter of 6 inches and a watertight cap fit flush with the ground. The underdrain shall tie into the overflow catch basin.

Bioretention swales follow all of the above design specifications for bioretention areas, but are shaped long and narrowly with perforated underdrain pipe(s) provided regardless of native soil infiltration rates.

Cross Section, Bioretention Area
Permeable Asphalt

Purpose/Definition

Permeable asphalt consists of a porous surface course supported by a uniformly graded stone bed which provides stormwater management. The permeable asphalt consists of standard bituminous asphalt in which the fines content has been screened and reduced in order to increase permeability. Permeable asphalt is placed directly on the stone bed in lightly compacted lifts of 2.5 – 3 inches.

Permeable asphalts have benefits including but not limited to the reduction of stormwater runoff rate and volume, reduction of loads of some pollutants in surface runoff by reducing the volume of stormwater leaving a site, and saving site area by using parking and driving areas as a treatment facility. Permeable asphalt is similar in application, limitations and maintenance to pervious concrete, however differs significantly in the product specifications, construction, and finished appearance. When properly designed, permeable asphalt systems provide an effective tool for the control of stormwater volume and peak flow rates.

Application

Permeable asphalt is similar in appearance to standard asphalt and has benefitting in recent years due to research regarding the use of additives and higher-grade binders to improve performance. Permeable asphalt is suitable in any climate where regular asphalt is appropriate.

Permeable asphalt is ideal for parking lots, sidewalks, walking paths, playgrounds, tennis courts, plazas and other comparable use areas. Permeable asphalt can be used in low-traffic roadways, but should be avoided on roadways carrying more than 25,000 vehicles per day. It should be noted that permeable asphalt is used in some highway settings to reduce standing water on the road. This use is specifically for safety reasons, does not provide water quality benefits, and is not relevant to the use of permeable asphalt as a BMP/LID measure.

Permeable asphalt can be used in residential, commercial, and institutional applications in both rural and urban environments. Permeable asphalt should be limited in industrial use where materials may be stockpiled or stored.

Limitations

Limitations of permeable asphalt include site selection and underlying soil permeability. Parking lots and light use residential streets are ideal for permeable asphalt. Roadways with more traffic will need a thicker section resulting in higher cost.
Grading and infiltration need to be considered early in the design process to assure effectiveness. Permeable asphalt with infiltration beds should be placed as level as possible but mild slopes (<3%) are acceptable. Soil permeability of at least 0.6 in/hr is required for infiltration. Permeable asphalt may be applied on sites with less permeable soils when combined with underdrains, however many of the flood control and water quality benefits may be reduced.

**Maintenance**

Typical maintenance activities and frequencies include:

- Biannual vacuuming of asphalt, at minimum
- Biannual inspection and cleaning of any inlets draining towards infiltration bed
- Maintain any planted areas adjacent to permeable asphalt to prevent soil washout and clogging of asphalt pores. Planted areas should be inspected semiannually to ensure that there are no bare or unstable spots in the landscape.
- Do not allow construction staging, soil/mulch stockpiling on unprotected asphalt

Periodic maintenance of permeable asphalt will aid in keeping the asphalt surface and/or underlying infiltration bed from being clogged with fine sediments. Compressed air units and other washing systems are not recommended. Inlet structures draining to infiltration bed should also be inspected and/or cleaned out on a biannual basis.

**General Design Guidelines**

A pervious asphalt system consists of a pervious surface course underlain by a storage reservoir placed upon uncompacted subgrade to aid assist stormwater infiltration or upon a filter layer with subdrains. The storage reservoir consists of a stone bed of uniformly graded and clean-washed coarse aggregate, typical 1/2 to 2 inches in size. A layer of nonwoven geotextile filter fabric can be used to separate the aggregate from the underlying soil, prohibiting the movement of fines into the bed.

The permeable asphalt surface should be as level as possible and should not have a slope greater than 3 percent. Bed bottoms should be level and uncompacted to allow for an even flow of the infiltrated stormwater. On sloped sites, beds should be constructed using a terraced design.

Permeable asphalts are flexible to various soil conditions. In sites with low soil permeability, the system should include underdrains placed in a filter bed under the storage reservoir to discharge the infiltrated runoff into the storm drainage system. All systems shall be designed with an overflow system which prevents water within the subsurface storage bed to pond above the level of the asphalt surface. The design should
include consideration of stormwater runoff from the pervious asphalt in the event that its performance is compromised or for extreme storm events.

**General Design and Sizing Specifications**

Surface area depends on storage volume requirements and permeability of the underlying native soil. Runoff volume is based on local regulatory requirements such as a specific design storm (e.g. 2-year, 24 hour) or total runoff (85th percentile).

The permeable asphalt area necessary to capture the design volume \( V_{\text{BMP}} \) is determined by calculating the area needed to store the design volume at the maximum depth \( b_{TH} \), taking into account the accessible storage area within the gravel pore space. The depth of the gravel storage reservoir should not exceed 12 inches for either infiltration or filtration designs. The area can be calculated by using the following formula:

\[
A (ft^2) = \frac{V_{\text{BMP}} (ft^3)}{b_{TH} (in) \times \frac{R_g}{12} \text{ in/ft}}
\]

where
- \( A = \) BMP surface area \((ft^2)\)
- \( V_{\text{BMP}} = \) BMP design volume \((ft^3)\)
- \( b_{TH} = \) reservoir depth \((in)\), and
- \( R_g = \) gravel void ratio (usually 0.4)

The area calculation assumes a level (slopes less than 3%) surface.

The underlying infiltration bed is typically 12 – 36 inches deep and comprised of clean, uniformly graded aggregate with approximately 40% void space. AASHTO No. 57 gravel is often used. Depending on local aggregate sources, both smaller and larger aggregate may be used as long as the aggregate is uniformly graded, clean and contains 40% void space.

**Minimum Pervious Asphalt Pavement Thickness Required to Bear Structural Load on Poor Subgrade with CBR* 2 (Ferguson, 2005)**

<table>
<thead>
<tr>
<th>Traffic Category</th>
<th>Avg. ESAL* per day</th>
<th>Porous Asphalt Surface Course Thickness (in)</th>
<th>Aggregate Base Course Thickness (in)</th>
<th>Total Thickness (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (parking lots, residential streets)</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>Medium Light (city business streets)</td>
<td>20</td>
<td>4.5</td>
<td>13</td>
<td>17.5</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>5</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>5000</td>
<td>7</td>
<td>22</td>
<td>29</td>
</tr>
</tbody>
</table>

*CBR is California Bearing Ratio; ESAL is Equivalent Single Axle Load = 18,000 pounds
Minimum Total Pervious Asphalt Pavement Thickness (aggregate base course + pervious asphalt surface course) Required to Bear Structural Load on Various Subgrades (Ferguson, 2005)

<table>
<thead>
<tr>
<th>Traffic Load</th>
<th>Subgrade CBR* 6 to 9</th>
<th>Subgrade CBR* 10 to 14</th>
<th>Subgrade CBR* 15 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (ESAL* 5 less per day)</td>
<td>9</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Medium Light (1,000 vpd max., ESAP 6 to 20 per day)</td>
<td>11</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Medium (3,000 vpd max., ESAL* 21 to 75 per day)</td>
<td>12</td>
<td>9</td>
<td>7</td>
</tr>
</tbody>
</table>

*CBR is California Bearing Ratio; ESAL is Equivalent Single Axle Load = 18,000 pounds

Permeable Hot-Mix Asphalt Pavement Sample Project Specifications

The language below is a sample of the specifications for permeable asphalt. These specifications should be modified to reflect specific project objectives and constraints, and should be confirmed by a structural engineer as suitable for the anticipated loads on the concrete.

A. Open graded asphalt shall be used [as indicated on the Drawings].

B. Bituminous Asphalt Cement.
   1. 5.75% to 6% by weight dry aggregate.
   2. Drain down of asphalt binder shall be no greater than 0.3% in accordance with ASTM D6390.
   3. Use a neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 64-10.
      a. Elastomeric polymer shall be a styrene-butadine-styrene or equal applied at a rate of 3% by total weight of the binder.
         Polymer and binder shall be thoroughly blended at the asphalt refinery prior to loading and transportation.
         The polymer modified asphalt binder shall be heat and storage stable.
   4. Add hydrated lime at a rate of 1% by weight of the total dry aggregate to mixes with granite stone to prevent separation of the asphalt from the aggregate.
      a. Tensile strength ratio shall be at least 80%.
      b. Hydrated lime shall meet the requirements of ASTM C977.
5. Test asphalt mix for resistance to stripping by water per ASTM D3625. Add anti-stripping agents to asphalt if the estimated coating area is not above 95%.

C. Asphalt Aggregate:

<table>
<thead>
<tr>
<th>U.S. Standard Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>100</td>
</tr>
<tr>
<td>3/8</td>
<td>92-98</td>
</tr>
<tr>
<td>4</td>
<td>32-38</td>
</tr>
<tr>
<td>8</td>
<td>12-18</td>
</tr>
<tr>
<td>16</td>
<td>7-13</td>
</tr>
<tr>
<td>30</td>
<td>0-5</td>
</tr>
<tr>
<td>200</td>
<td>0-3</td>
</tr>
</tbody>
</table>

D. Aggregate Base

1. Coarse aggregate shall be ½- to 2-inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 3).

2. Aggregate Grading:

<table>
<thead>
<tr>
<th>U.S. Standard Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 ½”</td>
<td>100</td>
</tr>
<tr>
<td>2”</td>
<td>90-100</td>
</tr>
<tr>
<td>1 ½”</td>
<td>35-70</td>
</tr>
<tr>
<td>1”</td>
<td>0-15</td>
</tr>
<tr>
<td>½”</td>
<td>0-5</td>
</tr>
</tbody>
</table>

3. Choker Course: 3/8- to ¾- inch uniformly graded stone with a wash loss of no more than 0.5% (AASHTO size number 57).

a. Choker aggregate grading:

<table>
<thead>
<tr>
<th>U.S. Standard Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ½”</td>
<td>100</td>
</tr>
<tr>
<td>1”</td>
<td>95-100</td>
</tr>
<tr>
<td>½”</td>
<td>25-60</td>
</tr>
<tr>
<td>4</td>
<td>0-10</td>
</tr>
<tr>
<td>8</td>
<td>0-5</td>
</tr>
</tbody>
</table>

E. Special Requirements for Permeable Asphalt

1. Laying temperature of the mix shall be between 240 and 250 degrees F and ambient temperatures shall not be below 40 degrees F during the duration of paving activities.

2. Compaction of the surface course shall occur when the surface is cool enough to resist a ten ton roller.
a. No more than two passes shall be made for compaction to preserve surface course porosity.

3. Install one inch thick choker course evenly over the surface of coarse aggregate base.

References


Pervious Concrete

Purpose/Definition

Pervious concrete was developed by the Florida Concrete Association and is most widely found in the southern states. Similar to permeable asphalt, pervious concrete is produced by reducing the amount of fines in the concrete mix in order to create voids for drainage. Pervious concrete should be underlain with a stone infiltration bed designed for stormwater management and should not be placed directly on a soil bed.

While permeable asphalt is similar in appearance and applicability to pervious concrete, pervious concrete has a coarser texture and a clean-swept finish can not be attained. A potential advantage to pervious concrete is the ability to introduce color to the mix. This allows the concrete surface to integrate aesthetically to the surrounding landscape.

Pervious concrete has benefits including but not limited to reduction of stormwater runoff peak rate and volume, reduction of loads of some pollutants in surface runoff by reducing the volume of stormwater leaving a site, and saving site area by using parking and driving areas as a treatment facility. When properly designed, pervious concrete systems provide an effective tool for the control of stormwater volume and peak flow rates.

Application

Pervious concrete is ideal for parking lots, sidewalks, walking paths, playgrounds, tennis courts, plazas and other comparable use areas. Pervious concrete can be used in low-traffic roadways, but should be avoided on roadways carrying more than 25,000 vehicles per day.

Pervious concrete can be used in residential, commercial, and institutional applications in both rural and urban environments. Pervious concrete should be limited in industrial use where materials may be stockpiled or stored as well as high traffic roadways such as highways.

Limitations

Limitations of pervious concrete include site selection and underlying soil permeability. Parking lots and light use residential streets are ideal for pervious concrete. Roadways with more traffic will need a thicker section resulting in higher cost.

Grading and infiltration need to be considered early in the design process to assure effectiveness. Pervious concrete with infiltration beds should be placed as level as possible but mild slopes (<3%) are acceptable. Soil permeability of at least 0.5 in/hr is
required for infiltration. Less permeable soils can be combined with underdrains, however some of the water quality and flood control benefits may be lost.

**Maintenance**

Typical maintenance limitations, activities and frequencies include:

- At least biannual vacuuming of concrete
- Biannual inspection and cleaning of any inlets draining towards infiltration bed
- Maintain any planted areas adjacent to pervious concrete to prevent soil washout and clogging of pores. Planted areas should be inspected semiannually to ensure that there are no bare or unstable spots in the landscape.
- Do not allow construction staging, soil/mulch stockpiling on unprotected concrete

Periodic maintenance of pervious concrete will aid in keeping the surface and/or underlying infiltration bed from being clogged with fine sediments. The concrete surface should be vacuumed biannually with a commercial cleaning unit. Compressed air units and other washing systems are not recommended. Inlet structures draining to the pervious concrete infiltration bed should also be inspected and/or cleaned out on a biannual basis.

**General Design Guidelines**

A pervious concrete system consists of a pervious surface course of concrete underlain by an infiltration bed (i.e. storage reservoir) placed upon uncompacted subgrade or upon a filter layer with subdrains. The storage reservoir consists of a stone bed of uniformly graded and clean-washed coarse aggregate, 1-1/2 to 2-1/2 inches in size. A layer of nonwoven geotextile filter fabric should be used to separate the aggregate from the underlying soil, prohibiting the movement fines into the bed.

The pervious concrete surface should be as level as possible and should not have a slope greater than 3 percent. Storage bed bottoms should be level and uncompacted to allow for an even flow of the infiltrated stormwater. On sloped sites, beds should be constructed using a terraced design.

Pervious concrete is flexible to various soil conditions. In sites with low soil permeability, the system should include underdrains placed in a filter bed under the storage reservoir to discharge the infiltrated runoff into the storm drainage system. All systems shall be designed with an overflow system which prevents water within the subsurface storage bed to pond above the level of the concrete surface. The design should include consideration of stormwater runoff from the pervious concrete in the event that its performance is compromised or for extreme storm events.
**Design and Sizing Specifications**

Pervious concrete shall be Portland cement Type II or V conforming to ASTM C150 or Portland cement Type IP or IS conforming to ASTM C595. The concrete should have a surface-void content of 15-25%. Detailed specifications for Pervious Concrete have been developed by the American Concrete Institute. Specific project specifications for pervious concrete should call for all work to conform to all requirements of ACI 522.1, ‘Specification for Pervious Concrete Pavement,’ published by the American Concrete Institute, Farmington Hills, Michigan [except as modified by Contract Documents].

Surface area depends on storage volume requirements and permeability of the underlying native soil. Runoff volume is based on local regulatory requirements defining the water quality volume such as a specific design storm (e.g. 2-year, 24 hour) or total runoff (85th percentile).

The pervious concrete area necessary to capture the design volume ($V_{BMP}$) is determined by calculating the area needed to store the design volume at the maximum depth ($b_{TH}$), taking into account the accessible storage area within the gravel pore space. The depth of the gravel storage reservoir should not exceed 12 inches. The area can be calculated by using the following formula:

$$A (ft^2) = \frac{V_{BMP} (ft^3)}{b_{TH} (in) \cdot \frac{R_g}{12 \frac{in}{ft}}}$$

where $A = BMP$ surface area ($ft^2$)

$V_{BMP} = BMP$ design volume ($ft^3$)

$b_{TH} = reservoir$ depth (in), and

$R_g = gravel$ void ratio (usually 0.4)

The area calculation assumes a level (slopes less than 3%) surface.

The underlying infiltration bed should be 12 – 36 inches deep and comprised of clean, uniformly graded aggregate with approximately 40% void space. AASHTO No. 57 gravel is appropriate. Depending on local aggregate sources, both smaller and larger aggregate may be used, as long as the aggregate is uniformly graded, clean and contains 40% void space.
Pervious Concrete Mixture Sample Specification Language

The language below is a sample of the specifications for concrete mixture proportions. This specifications below do include some superfluous information, which is intended for informational purposes for the use and applicability of these specifications. These specifications should be modified to reflect project objectives and constraints, and should be confirmed by a structural engineer as suitable for the anticipated loads on the concrete.

The Contractor shall furnish a proposed mixture design, with proportions of materials, or if mixture proportions are proprietary, a written submittal from the concrete supplier, prior to commencement of work. The data shall include densities determined in accordance with ASTM C 29 section 11, Jigging Procedure. The composition of the proposed concrete mixture shall be submitted to the Architect/Engineer for review and/or approval and shall comply with the following provisions unless an alternative composition is demonstrated to comply with the project requirements. Mixture performance will be affected by the properties of the particular materials used. Trial mixtures must be tested to establish proper proportions and determine expected behavior. Concrete producers may have mixture proportions for pervious concrete optimized for performance with local materials. General mixture recommendations are as follows:

1) Concrete mixture density: range of 105 lb/ft³ to 130 lb/ft³ (1682 kg/m³ to 2082 kg/m³) per ASTM C 29, section 11, Jigging Procedure.

2) Concrete mixture void content: range of 15% to 25%, per ASTM C 138, Gravimetric Air Determination.

3) Cementitious content: range of 450 lbs/yd³ to 550 lb/yd³ (267kg/m³ to 326kg/m³)

4) Supplementary cementitious content: Fly ash: 20% maximum; combined supplementary cementitious content: 20% maximum.

5) Water-to-cement (cementitious) ratio: range from 0.26 to 0.35.

6) Aggregate content: The bulk volume of aggregate per cubic yard (cubic meter) shall be equal to 27ft³ (1000L) when calculated from the density (unit weight) determined in accordance with ASTM C 29 Jigging Procedure.

7) Admixtures: Admixtures shall be used in accordance with the manufacturers’ instructions and recommendations.

8) Mixture Water: The quantity of mixing water shall be established to produce a pervious concrete mixture of the desirable workability to facilitate placement, compaction, and finishing to the desired surface characteristics. Mixture water shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (A cement paste with a dull-dry appearance has insufficient mixture water for hydration.) Insufficient mix water results in inconsistency in the mix and poor bond strength. High water content may result in the
paste sealing the void system primarily at the bottom and poor bond at the upper surface.

9) Air Entrainment: has been shown to increase freeze thaw durability of pervious concrete.

10) Fiber Reinforcement: may help prevent raveling but may decrease workability.

References

American Concrete Institute, ‘Specification for Pervious Concrete Pavement,’ ACI 522.1, Farmington Hills, Michigan, March, 2008.


Rooftop Disconnection

Purpose/Definition
Rooftop disconnection involves directing runoff from downspouts to pervious areas (vegetated open space, a mulched bed, pervious pavement or other BMP) where flow can soak into or filter over the ground. This disconnects the rooftop from the storm drain system and reduces both runoff volume and pollutants delivered to receiving waters. To function well, rooftop disconnection is dependent on well suited site conditions (sufficient flow path length, soils, slopes, etc). Where site conditions are not ideal, however, rooftop disconnection may be used in combination with other BMPs (soil amendment, biofiltration, etc.) to achieve water quality treatment or runoff volume goals.

It should be noted that this BMP/LID refers specifically to the qualitative approach of directing roof runoff to pervious surfaces. This practice, as described herein, does not meet the retention requirements of the slope infiltration method described in the Santa Cruz County Design Criteria.

Application
There are many opportunities for disconnecting rooftops in both new and redevelopment designs. Simply extending existing downspouts to existing pervious surfaces may be a low cost retrofit available to many existing structures. For new or redeveloped areas, runoff may be directed to undisturbed natural areas or landscaped areas in commercial, industrial, and residential settings if design specifications can be met.

Limitations
The following constraints are critical when considering the use of rooftop disconnection to capture and treat stormwater runoff for new developments:

- **Space:** As a general rule, the treatment area should be 10% of the roof areas draining to the downspout (Portland BES, 2010); however for low permeability soils, a larger discharge area may be required.

- **Topography:** Runoff must be conveyed as sheetflow from the downspout across open areas to maintain proper disconnection. See design specifications.

- **Soils:** Downspout disconnections work best in undisturbed, sandy soils that allow runoff to infiltrate. Clayey soils or soils that have been compacted by construction equipment greatly reduce the effectiveness of this practice and soil amendments may be needed. Depending on detailed design of downspout outlets, splash blocks, rocks, or stone at the end of downspouts to direct runoff and control erosion may be required.
Maintenance

Maintenance of areas receiving disconnected runoff is generally no different than that required for other lawn or landscaped areas. The areas receiving runoff should be protected from future compaction (e.g., by planting trees or shrubs along the perimeter). Large amounts of foot traffic should be discouraged in areas receiving runoff.

Design Specifications

The following specifications should be applied for the design of rooftop disconnection to capture and treat stormwater runoff for new developments:

- Runoff must be conveyed as sheetflow from the downspout across open areas to maintain proper disconnection. Level spreaders may be needed at the downspout to dissipate flow. Additionally, disconnected downspouts should be located on gradual slopes (≤ 5%) and directed away from buildings to maintain sheetflow and prevent water damage to basements and foundations. If slopes are too steep (> 5%), a series of terraces or berms, spreaders, or surface protection may be required.

- Disconnection must ensure no basement seepage. Downspouts and any extensions should extend a minimum of six feet from a basement and two feet from a crawl space or concrete slab. Longer extensions are recommended where feasible. Extensions can also be accomplished through the use of pop-up drain emitters, if desired, installed per manufacturer’s specifications.

- Downspout outlets must be at least 10 feet away from the nearest downslope impervious surface to discourage ‘re-connections’.

- The rooftop contributing area shall be no more than 1,000 sq. feet per disconnected downspout.

- The disconnections should drain continuously through a vegetated area or filter strip to the property line or structural stormwater control with a recommended minimum treatment area of 10% of the tributary area.

- If smaller treatment areas are anticipated, then a secondary BMP should be designed to receive flows and enhance treatment (i.e., bioretention/rain garden), see Figure 2.

- Disconnections are acceptable on relatively permeable soils (hydrologic soil groups A and B) without soil testing.

- In less permeable soils (hydrologic soil groups C and D, permeability less than 0.6 in/hr), secondary BMPs (spreading device, soil amendment, bioretention, etc) are required to achieve treatment objectives.
Figure 1: Methods For Disconnecting Downspouts and Spreading Flow

Sources:

City of Portland Environmental Services, *Downspout Disconnections (splashblock disconnection).*
http://www.portlandonline.com/bes/index.cfm?c=31870&a=127466


**Sidewalk Storage**

**Purpose/Definition**

Sidewalk storage is the practice of increasing the ability for sidewalks to store, treat, and/or infiltrate stormwater runoff. This may be achieved via the selection of sidewalk material (i.e. using pervious concrete or pavers for sidewalk surface), by integrating vegetation with sidewalks via planter boxes/areas, and/or by underlaying sidewalks with a material able that encourages plant growth (i.e. structural soil). Pervious concrete and pavers are considered BMP/LID measures in their own right, and are not explored further herein.

Integrating planting areas for trees and shrubs adjacent to (or within) sidewalks is a common BMP practice. A variety of methods for this integration exist, and the Santa Cruz County Design Criteria includes specifications for tree planting in tree wells or planting strips (see Figure ST-9a). Other potential types of vegetated sidewalk storage BMPs include integrated planting areas, and flow through planters.

Generally, the foundation material for pavements and sidewalks must be compacted to a degree that no longer supports root growth. Structural soil was developed at Cornell University, and is a patented mixture of material which can withstand the compaction necessary to provide pavement stability for sidewalks and pavements, while providing ample rooting area for street tree roots to grow. Correctly applied, structural soil can decrease tree mortality and sidewalk failure.

**Application**

The intent of this BMP is to manage stormwater from the immediate vicinity. Sidewalk storage techniques are appropriate for the majority of new sidewalk projects. Sidewalk storage can be used in residential, commercial, and business applications in both rural and urban environments. The use of structural soil under sidewalks creates a reservoir which both allows for storage, detention, and infiltration of surface runoff, as well as the establishment of tree and shrub roots, which aids in vegetations stability and water quality treatment.
Limitations

Limitations of sidewalk storage include site selection and underlying soil permeability. Soil permeability of at least 0.6 in/hr is required for infiltration. For sites with low soil permeability, the system should include underdrains placed in the structural soil to discharge the infiltrated runoff into the storm drainage system. Alternatively, the structural soil reservoir basin may be designed to capture runoff for a severe (i.e. 100-year) design storm. All systems shall be designed with an overflow system which prevents water within the subsurface storage bed to pond above the level of the anticipated root zone. The design should include consideration of stormwater runoff from the sidewalk in the event that its performance is compromised or for extreme storm events.

A level reservoir bed for the structural soil is recommended, and the bed should not have a slope greater than 3 percent. Bed bottoms should be level and uncompacted to allow for an even flow of the infiltrated stormwater. On sloped sites, beds should be constructed using a terraced design.
Maintenance

Structural soil itself is very low maintenance. When overlain by a pervious surface, that surface must undergo required maintenance to ensure the ongoing benefit of the structural soil. Vegetation must be maintained per general landscaping specifications; which may include soil specifications, irrigation needs, pest control and pruning.

Design Specifications

A minimum 24" depth of structural soil is recommended for optimum healthy tree root development.

These structural soil specifications are provided for informational purposes and are presented “as is” from resources provided by the manufacturers. CU-Soil is a patented material and must be purchased from a licensed supplier. Amereq (http://www.amereq.com/) licenses the manufacturing of CU-Soil to ensure quality control of installations. Carolina Stalite is composed primarily of a manufactured component available from Carolina Stalite Company (Salisbury, NC). It is available through the horticultural division of Carolina Stalite (www.permatill.com).
1.01 SAMPLES AND SUBMITTALS

A. At least 30 days prior to ordering materials, the Contractor shall submit to the Engineer representative samples, certificates, manufacturers' literature and certified tests for materials specified below. No materials shall be ordered until the required samples, certificates, manufacturers' literature and test results have been reviewed and approved by the Engineer. Delivered materials shall closely match the approved samples. Approval shall not constitute final acceptance. The Engineer reserves the right to reject, on or after delivery, any material that does not meet these specifications.

B. Submit two - one half cubic foot representative samples of Clay Loam and two - two cubic foot representative samples Structural Soil mixes in this section for testing, analysis and approval. Submit one set of samples for every 500 CY of material to be delivered. In the event of multiple source fields for Clay Loam, submit a minimum of one set of samples per source field or stockpile. Samples shall be taken randomly throughout the field or stockpile at locations as directed by the Engineer and packaged in the presence of the Engineer. Contractor shall deliver all samples to testing laboratories and shall have the test results sent directly to the Engineer. Samples shall be labeled to include the location of the source of the material, the date of the sample and the Contractor's name. One of the two samples is to be used by the testing laboratory for testing purposes. The second sample of all Clay Loam and Structural Soil shall be submitted to the Engineer at the same time as test analysis as a record of the soil color and texture.

1. Submit the locations of all source fields for Clay Loam.
2. Submit a list of all chemicals and herbicides applied to the Clay Loam for the last five years and a list of all crops grown in the Clay Loam source fields for the last three years.

C. Submit soil test analysis reports for each sample of Clay Loam and Structural Soil from an approved soil-testing laboratory. The test results shall report the following:

1. The soil testing laboratory shall be approved by the Engineer. The testing laboratory for particle size and chemical analysis may be a public agricultural extension service agency or agricultural experiment station.
2. Submit a particle size analysis including the following gradient of mineral content:

USDA Designation Size in mm.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>+2 mm</td>
</tr>
<tr>
<td>Sand</td>
<td>0.05 - 2 mm</td>
</tr>
<tr>
<td>Silt</td>
<td>0.002 - 0.05 mm</td>
</tr>
<tr>
<td>Clay</td>
<td>minus 0.002 mm</td>
</tr>
</tbody>
</table>

Sieve analysis shall be performed and compared to USDA Soil Classification System.

D. Submit a chemical analysis, performed in accordance with current AOAC Standards, including the following:
   a. pH and Buffer pH.
   b. Percent organic matter as determined by the loss of ignition of oven dried samples.
   c. Analysis for nutrient levels by parts per million including nitrate nitrogen, ammonium nitrogen, phosphorus, potassium, magnesium, manganese, iron, zinc, calcium and extractable aluminum. Nutrient test shall include the testing laboratory recommendations for supplemental additions to the soil as calculated by the amount of material to be added per volume of soil for the type of plants to be grown in the soil.
   d. Analysis for levels of toxic elements and compounds including arsenic, boron, cadmium, chromium, copper, lead mercury, molybdenum, nickel, zinc and PCB. Test results shall be cited in milligrams per kilogram.
   e. Soluble salt by electrical conductivity of a 1:2 soil/water sample measured in Millimho per cm.
   f. Cation Exchange Capacity (CEC).

1. Submit 5-point minimum moisture density curve AASHTO T 99 test results for each Structural Soil sample without removing oversized aggregate.

2. Submit California Bearing Ratio test results for each Structural Soil sample compacted to peak standard density. The soaked CBR shall equal or exceed a value of 50.

3. Submit measured dry-weight percentage of stone in the mixture.

4. The approved Structural Soil samples shall be the standard for each lot of 500 cubic yards of material.
5. All testing and analysis shall be at the expense of the Contractor.

1.02 DELIVERY, STORAGE, AND HANDLING
A. Do not deliver or place soils in frozen, wet, or muddy conditions. Material shall be delivered at or near optimum compaction moisture content as determined by AASHTO T 99 (ASTM D 698). Do not deliver or place materials in an excessively moist condition (beyond 2 percent above optimum compaction moisture content as determined by AASHTO T 99 (ASTM D 698).

B. Protect soils and mixes from absorbing excess water and from erosion at all times. Do not store materials unprotected from large rainfall events. Do not allow excess water to enter site prior to compaction. If water is introduced into the material after grading, allow material to drain or aerate to optimum compaction moisture content.

MATERIALS

2.01 CLAY LOAM
A. Clay Loam / Loam shall be a "loam to clay loam" based on the "USDA classification system" as determined by mechanical analysis (ASTM D-422) and it shall be of uniform composition, without admixture of subsoil. It shall be free of stones greater than one-half inch, lumps, plants and their roots, debris and other extraneous matter over one inch in diameter or excess of smaller pieces of the same materials as determined by the Engineer. It shall not contain toxic substances harmful to plant growth. It shall be obtained from areas which have never been stripped of top soil before and have a history of satisfactory vegetative growth. Clay Loam shall contain not less than 2% nor more than 5% organic matter as determined by the loss on ignition of oven-dried samples.

B. Mechanical analysis for a Loam / Clay Loam shall be as follows:

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>% of total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>less than 5%</td>
</tr>
<tr>
<td>Sand</td>
<td>20 - 45%</td>
</tr>
<tr>
<td>Silt</td>
<td>20 - 50%</td>
</tr>
<tr>
<td>Clay</td>
<td>20 - 40%</td>
</tr>
</tbody>
</table>

C. Chemical analysis: Meet or be amended to meet the following criteria.
1. pH between 6.0 to 7.6
2. Percent organic matter 2 -5% by dry weight.
3. Nutrient levels as required by the testing laboratory recommendations for the type of plants to be grown in the soil.
4. Toxic elements and compounds below the United States Environmental Protection Agency Standards for Exceptional
Quality sludge or local standard; whichever is more stringent.
5. Soluble salt less than 1.0 Millimho per cm.
6. Cation Exchange Capacity (CEC) greater than 10

2.02 CRUSHED STONE
A. Crushed Stone shall be a DOT certified crushed stone. Granite and limestone have been successfully used in this application. Ninety-100 percent of the stone should pass the 1.5 inch sieve, 20-55 percent should pass the 1.0 inch sieve and 10 percent should pass the 0.75 inch sieve. A ratio of nominal maximum to nominal minimum particle size of 2 is required
B. Acceptable aggregate dimensions will not exceed 2.5:1.0 for any two dimensions chosen.
C. Minimum 90 percent with one fractured face, minimum 75 percent with two or more fractured faces.
D. Results of Aggregate Soundness Loss test shall not exceed 18 percent. Losses from LA Abrasion tests shall not exceed 40%.

2.03 HYDROGEL
A. Hydrogel shall be a potassium propenoate-propenamide copolymer Hydrogel or equivalent such as that which is manufactured under the name Gelscape by Amereq Corporation. (800) 832-8788

2.04 WATER
A. The Contractor shall be responsible to furnish his own supply of water to the site at no extra cost. All work injured or damaged due to the lack of water, or the use of too much water, shall be the Contractor’s responsibility to correct. Water shall be free from impurities injurious to vegetation.

2.05 STRUCTURAL SOIL
A. A uniformly blended mixture of Crushed Stone, Clay Loam and Hydrogel, mixed to the following proportion:

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>UNIT OF WEIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Stone Loam (screened)</td>
<td>80 units dry weight as determined by the test of the mix. (Approx. 20 units dry weight)</td>
</tr>
<tr>
<td>Hydrogel</td>
<td>0.03 units dry weight/100 units stone (AASHTO T-99 optimum moisture)</td>
</tr>
</tbody>
</table>

B. The initial mix design for testing shall be determined by adjusting the ratio between the Crushed Stone and the Clay loam. Adjust final mix
dry weight mixing proportion to decrease soil in mixture if CBR test results fail to meet acceptance (CBR > 50).

CONSTRUCTION METHODS

3.01 SOIL MIXING AND QUALITY CONTROL TESTING

A. All Structural Soil mixing shall be performed at the Contractor’s yard using appropriate soil measuring, mixing and shredding equipment of sufficient capacity and capability to assure proper quality control and consistent mix ratios. No mixing of Structural Soil at the project site shall be permitted. Portable pugging may be used

1. Maintain adequate moisture content during the mixing process. Soils and mix components shall easily shred and break down without clumping. Soil clods shall easily break down into a fine crumbly texture. Soils shall not be overly wet or dry. The contractor shall measure and monitor the amount of soil moisture at the mixing site periodically during the mixing process.

2. A mixing procedure for front-end loader shall be as follows:

   a. On a flat asphalt or concrete paved surface, spread an 8 inch to 12 inch layer of crushed stone.
   b. Spread evenly over the stone the specified amount of dry hydrogel. Water the hydrogel on the stone before adding the soil.
   c. Spread over the hydrogel and crushed stone a proportional amount of clay loam according to the mix design.
   d. Blend the entire amount by turning, using a front-end loader or other suitable equipment until a consistent blend is produced.
   e. Add moisture gradually and evenly during the blending and turning operation as required to achieve the required moisture content. Delay applications of moisture for 10 minutes prior to successive applications. Once established, mixing should produce a material within 1% of the optimum moisture level for compaction.

3. A pugging operation mixing procedure may be as follows:

   a. Feed a known weight of crushed stone into the mixing trough.
   b. Add hydrogel as a slurry into trough and mix slurry and stone into a uniform blend.
   c. Meter in soil in proper proportion of Clay loam soil
While stone-slurry mixture is in motion.

d. Add water to bring mixture to target moisture content after factoring in water from the slurry and the Clay-loam moisture.

e. Auger out to stock pile or transport vehicle (or into pit if using a portable pugging operation).

B. The Contractor shall mix sufficient material in advance of the time needed at the job site to allow adequate time for final quality control testing as required by the progress of the work. Structural Soil shall be stored in piles of approximately 500 cubic yards and each pile shall be numbered for identification and quality control purposes. Storage piles shall be protected from rain and erosion by covering with plastic sheeting.

C. During the mixing process, the Contractor shall take two - one cubic foot quality control samples per 500 cubic yards of production from the final Structural Soil. The samples shall be taken from random locations in the numbered stockpiles as required by paragraph 1.03.B of this specification. Each sample shall be tested for particle size analysis and chemical analysis as described in Paragraph 1.03.C.2 and 3 above. Submit the results directly to the Engineer for review and approval.

D. The quality control sample Clay Loam-Crushed Stone ratio’s shall be no greater or less than 2% of the approved test sample as determined by splitting a known weight of oven dried material on a #4 sieve. In the event that the quality control samples vary significantly from the approved Structural Soil sample, as determined by the Engineer, remix and retest any lot of soil that fails to meet the correct analysis making adjustments to the mixing ratios and procedures to achieve the approved consistency.

3.02 INSTALLATION OF STRUCTURAL SOIL MATERIAL

A. Install Structural Soil in 8 inch lifts and compact each lift. (Minimum of 24" total structural soil depth, preferably 36" recommended).

B. Compact all materials to peak dry density from a standard AASHTO compaction curve (AASHTO T 99). No compaction shall occur when moisture content exceeds maximum as listed herein. Delay compaction 24 hours if moisture content exceeds maximum allowable and protect Structural Soil during delays in compaction with plastic or plywood as directed by the Engineer.

C. Bring Structural Soils to finished grades as shown on the Drawings. Immediately protect the Structural Soil material from contamination by toxic materials, trash, debris, water containing cement, clay, silt or
materials that will alter the particle size distribution of the mix with plastic or plywood as directed by the Engineer.

D. The Engineer may periodically check the material being delivered and installed at the site for color and texture consistency with the approved sample provided by the Contractor as part of the submittal for Structural Soil. In the event that the installed material varies significantly from the approved sample, the Engineer may request that the Contractor test the installed Structural Soil. Any soil which varies significantly from the approved testing results, as determined by the Engineer, shall be removed and new Structural Soil installed that meets these specifications.
Carolina Stalite Structural Soil Specification

Section 02911 INSTALLATION GUIDELINES –
STALITE STRUCTURAL SOIL MIX FOR TREES

PART 1 - GENERAL

PART 2 - PRODUCTS

2.1 MATERIALS

A. STRUCTURAL SOIL MIX

1. The Structural Soil Mix shall be Stalite Structural Soil Mix (a special pre-mixed blend of 80% 3/4” graded “STALITE” Expanded Slate Aggregate and 20% approved sandy clay loam).

B. TREE PIT BACKFILL PLANTING MIX

1. The tree pit backfill planting mix shall be high quality topsoil PermaTill mix.

PART 3 - EXECUTION

3.1 PREPARATION

A. GENERAL

1. The paving contractor shall obtain necessary approvals before placing each SSM layer.

2. The paving contractor shall use adequate numbers of skilled workmen who are thoroughly trained in the necessary crafts and are completely familiar with the specified requirements and methods needed for proper performance of the work in this section.

3. The contractor must provide access for and cooperate with the testing laboratory.

4. Adequacy of the final compaction of all elements requiring compaction shall be determined in the field by the engineer to achieve the minimum specified compaction level.

B. PREPARING SUBGRADE

1. The subgrade shall be prepared according to the following procedure:
   a. Remove all organic matter, debris, loose material and large rocks.
   b. Dig out soft and mucky spots and replace with suitable material.
   c. Loosen hard spots and uniformly compact the subgrade to 95% of its maximum dry density.
C. PERFORATED UNDERDRAIN SYSTEM

1. The underdrain system shall be installed, including sock or soil separator fabric, according to drawing and specifications, and connected to the storm drain.

3.2 PLACING STRUCTURAL SOIL MIX BY PAVING CONTRACTOR

A. GENERAL

1. Adequacy of the final compaction shall be determined in the field by the engineer by proof roll.

2. The soil vents and drains shall be installed as specified and structural soil compacted under and around each pipe.

3. Optional – If wooden tree pit forms are used, they shall be installed as directed by the Landscape Architect.

4. The SSM shall be placed in approximately uniform lifts over the entire area of project and each lift compacted, including the open tree pit areas. Construction equipment, other than for compaction, shall not operate on the exposed structural soil mix. Over-compaction should be avoided. No foot or equipment traffic should be allowed on the compacted material until the paving is placed.

5. The drip irrigation system is to be installed and tested during the installation to avoid disturbing the compaction of the mix.

B. COMPACTING

1. Use of portable vibratory plate compacting machine (Recommended)

   a. Place structural soil mix in horizontal lifts not exceeding 12 inches of compacted depth. Use a minimum of two passes, of not less than 10 seconds per pass, before moving the vibratory plate to the next adjacent location. Additional passes may be required and should be determined in the field by the engineer to insure stability of the layer. Continue placing and compacting 12" lifts until the specified depth is reached.

2. Use of vibratory steel roller (Recommended)

   a. For large spaces, a vibratory steel roller weighing no more than 12 tons static weight can be used. Horizontal lifts should not exceed 12" compacted. The minimum number of passes is two and maximum number is four. Additional passes may be required and should be determined in the field by the engineer to insure stability of the layer.
3.3 PLACING PLANTING MIX

A. GENERAL
   1. All necessary approvals shall be obtained from the contractor before placing the surface planting mix.
   2. Place planting mix directly on the structural soil.
   3. Do not place planting mix against the trunks of existing trees.

3.4 MULCH PLACEMENT

A. Mulch can be placed as specified directly on the compacted structural soil.

PART 4 - TREE PLANTING

4.1 PLANTING PIT PREPARATION BY LANDSCAPE CONTRACTOR

A. PLANTING PIT EXCAVATION

   1. The Landscape Contractor shall excavate the tree pit using these procedures:

      a. Excavate the structural soil mix to a depth equal to the height of the root ball of the tree to be planted. Remove the SSM to within two feet of the edge of the paved area.

      b. Place the tree in the pit and backfill as soon as possible, as recommended in section “B”. No tree pit shall remain excavated for more than 2 hours unless forms are used.

B. TREE PIT BACKFILL PLANTING MIX

   1. The landscape contractor shall backfill the tree pit by using these procedures:

      a. Remove any optional wooden forms. Immediately place the tree in the pit as detailed and mix the excavated structural soil 50:50 with the specified topsoil backfill planting mix in one foot lifts and tamp until firm.

      b. Tamp the planting mix in one foot lifts until the pit is filled to the specified grade above the planting.

      c. Dispose of the excavated structural soil mix (do not re-use as structural soil).

      d. Attach drip irrigation as specified.
PART 2 - PRODUCTS

2.1 STRUCTURAL SOIL

A. Provide a Structural Soil mix using the two components listed below that will meet the ASTM standards as follows:

- ¾” Stalite Expanded Slate 80%
- Sandy Clay Loam * 20%

*Percentages of sand and clay may vary to meet testing requirements

1. Air Filled Porosity: 10% - 15% by volume

2. Water Retention (ASTM D2325) at 0.1 bar: minimum of 10% - 12% by volume, up to 30%

3. Permeability (Hydraulic Conductivity) (ASTMD2434 or D5084): Minimum 1/4” - 1/2” per hour

2.2 Structural Soil Components

A. ¾” Stalite Rotary Kiln Expanded Slate

1. ASTM C29 Unit Dry Weight loose (48 lbs/cf to 55 lbs/cf)
Saturated Surface Loose (55 lbs/cf to 60 lbs/cf)

2. ASTM C127 Specific Gravity to meet 1.45 to 1.60 Dry Bulk

3. ASTM C330 to meet the ASTM Gradation 3/4” - #4 size

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1”</td>
<td>100</td>
</tr>
<tr>
<td>3/4”</td>
<td>90 - 100</td>
</tr>
<tr>
<td>3/8”</td>
<td>10-50</td>
</tr>
<tr>
<td>#4</td>
<td>0 - 10</td>
</tr>
</tbody>
</table>

4. Test for degradation loss using Los Angeles Abrasion testing in accordance with ASTM C-131 modified method FM 1-T096. No more than 28% of the weight of the aggregate must be lost to degradation.
1. Texture
   
   40%-65% sand
   15%-25% silt
   20%-35% clay
   2%-5% Organic matter

2.2 MIXING OFFSITE

A. Structural Soil

1. Mechanically mix the sand and loam thoroughly if mixing is necessary to meet the specifications.

2. Saturate the 3/4” Expanded Slate with water and mechanically mix the sandy clay loam until the slate particles are completely coated.

4. When stockpiling the finished mix, cover the pile with a plastic tarp to prevent drying out or soil separation from rain.

5. Install the mix within 48 hours of mixing.
Section 02911 INSTALLATION GUIDELINES –
STALITE STRUCTURAL SOIL MIX FOR TREES

PART 1 – GENERAL

PART 2 - PRODUCTS

2.1 MATERIALS

A. STRUCTURAL SOIL MIX

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B. TREE PIT BACKFILL PLANTING MIX

1. The tree pit backfill planting mix shall be high quality topsoil PermaTill mix.

PART 3 - EXECUTION

3.1 PREPARATION

A. GENERAL

1. The paving contractor shall obtain necessary approvals before placing each SSM layer.

2. The paving contractor shall use adequate numbers of skilled workmen who are thoroughly trained in the necessary crafts and are completely familiar with the specified requirements and methods needed for proper performance of the work in this section.

3. The contractor must provide access for and cooperate with the testing laboratory.

4. Adequacy of the final compaction of all elements requiring compaction shall be determined in the field by the engineer to achieve the minimum specified compaction level.

B. PREPARING SUBGRADE

1. The subgrade shall be prepared according to the following procedure:
   a. Remove all organic matter, debris, loose material and large rocks.
   b. Dig out soft and mucky spots and replace with suitable material.
   c. Loosen hard spots and uniformly compact the subgrade to 95% of its maximum dry density.
References


Street Design

Purpose/Definition

Street design offers numerous opportunities to reduce impervious surfaces and thus decrease runoff and associated stormwater management requirements. Areas of opportunity include the layout of streets, street width and drainage design.

Thoughtful site layout and design of streets helps achieve stormwater control ‘at the source’ which creates less runoff requiring management, less stormwater infrastructure, and less impact on downstream waterbodies. Reducing paving lowers development and maintenance costs. Forgoing curb-and-gutter in favor of a rural residential section results in major cost savings, while allowing for infiltration and attractive landscaping and bioretention.

Application

Street design can be used whenever new streets or significant street improvements are proposed.

Limitations

Narrowed or curbless street design may not be desirable for various reason (ex. desired traffic speed), and for re-design project, existing resident preferences should be weighed. Good drainage for road subgrade must be provided when using roadside infiltration methods. Soil and topography may limit street siting opportunities. Roadside swales can be difficult to accommodate in single family residential developments with net densities above 8 units per acre. Incorporating LID techniques into the re-design of existing streets may require acquisition of additional property, right of way, or easements.

Maintenance

Swales require periodic sediment removal to maintain volume and infiltration ability. If swales are landscaped, maintenance of that landscape, including removal of downed vegetation, is required. If swales are to function as bioretention swales, follow maintenance guidelines found in the LID information sheet for bioretention.
General Design Guidelines

Site Layout of Streets for New Developments

In new developments, road siting and street network layout are important considerations. To maximize stormwater filtration and infiltration, developers should aim to preserve natural drainage patterns whenever possible and avoid locating streets (and other impervious surfaces) in low areas or on highly permeable soils. For example, locate roads on ridge lines, allowing water to drain naturally downhill. Whenever possible, choose sites with the least permeable soils for roads in order to minimize the impact of the impervious surface of the road. While designers must consider development character and context when designing a street system, they also should be aware that the type of network selected affects the total amount of pavement. For example, a typical grid system of streets results in more total impervious area than a system with cul-de-sacs and loops.

Design Width

New streets should be designed with the minimum pavement width that will support the area’s traffic volume, on-street parking needs, and emergency and maintenance access.

A simple way to narrow a suburban residential street is to provide one parking lane rather than two. In especially low traffic areas, sidewalks may be restricted to one side of the street or, in certain situations, eliminated.

Street Drainage

While curb-and-gutter is often considered the “standard” in road design, it tends to amplify stormwater volume and velocity while discouraging infiltration and groundwater recharge. Curbless road design, such as the so-called “rural residential section”, encourages infiltration via roadside swales. Appropriate protection (such as guardrails) between the road and swale may be provided where necessary. On low-traffic streets without curbs, grass shoulders can serve as an occasional parking lane, allowing a narrower paved area. Subgrade drainage below grass shoulders may be a viable option with permeable soils (see Bioretention).

Runoff from street surfaces may also be decreased by using permeable pavement, described in detail in a separate LID information sheet.

Design Specifications

Design residential streets with the minimum pavement width necessary to support the traffic volume, parking needs, and emergency and maintenance access. Use shallow, grassed roadside swales instead of curb and gutter when net densities are 8 units per acre.
or less. Swales to catch road runoff should be sloped no more than 3:1. Limit sidewalks to one side on roads with less than 400 Average Daily Traffic (ADT) (or 200 ADT for cul-de-sacs). Take care not to compact adjacent, permeable soils during construction and protect swales from construction sediment or remove sediment after construction is complete. Additional specifications will be as designed by the project engineer.
Underground Retention
(Dry Wells/Infiltration Trenches/Arch Trenches)

Purpose/Definition
A ‘dry well’, sometimes called a ‘seepage pit’, is a subsurface storage facility that temporarily stores and infiltrates stormwater runoff from impervious surfaces. Impervious surfaces connect directly into the dry well, which may be either an excavated pit filled with uniformly graded aggregate wrapped in geotextile (dry well, infiltration trench) or a prefabricated storage chamber or perforated pipe segment (arch trench, wet vault). Underground retention facilities discharge the stored runoff via infiltration into the surrounding soils. By capturing runoff at the source, underground retention can dramatically reduce the increased volume of stormwater generated by impervious surfaces. By decreasing the volume of stormwater runoff, underground retention can also reduce runoff rate and improve water quality.

Application
Underground retention may be utilized at any roof or impervious area with relatively low sediment loading. With proper design considerations to capture or trap sediment, underground retention may be feasible in higher sediment load scenarios.

Limitations
The use of underground retention is applicable only where subgrade soils have the appropriate permeability rates to achieve complete draining of the retention volume within 48 hours. Like other BMPs that rely on infiltration, without additional design provisions underground retention methods are not appropriate for areas where high pollutant or sediment loading is anticipated, in groundwater supply locations, or where there is high groundwater due to the potential for groundwater contamination. Also, underground retention must not be used where their installation would create a significant risk for basement seepage or flooding, or interfere with the operation of subsurface sewage disposal systems.

Maintenance
Underground retention facilities should be inspected at least four times annually as well as after every storm exceeding 1 inch of rainfall. The water level in the test well should be the primary means of measuring infiltration rates and drain times. Removing stored runoff from an impaired or failed dry well can also be accomplished through the test well. Adequate inspection and maintenance access to the test well must be provided.

An underground retention maintenance plan must indicate the approximate time it would normally take to drain the maximum design storm runoff volume from the dry well. This normal drain time should then be used to evaluate the dry well’s actual performance. If significant increases in the normal drain time are observed or if it exceeds the 48 hour
design limit, appropriate measures must be taken to comply with the drain time requirements and maintain the proper functioning of the underground retention facility.

**Design Guidelines**

- Dry wells should drain-down within 48 hours.
- Dry wells typically consist of 18 to 48 inches of clean washed, uniformly graded aggregate with a maximum 40% void capacity (AASHTO No. 3, or similar). Dry well aggregate is wrapped in a nonwoven geotextile, which provides separation between the aggregate and the surrounding soil. At least 12 inches of soil is then placed over the dry well. An alternative form of dry well is a subsurface, prefabricated chamber. A variety of prefabricated dry wells are currently available on the market.
- Dry wells are not recommended when their installation would create a significant risk for basement seepage or flooding. In general, a minimum of 10 feet of separation is required between dry wells and building foundations. Shorter separation distances may require an impermeable liner to be installed on the building side of the dry well.
- All dry wells must be able to safely convey system overflows to downstream drainage systems. System overflows can be incorporated either as surcharge (or overflow) pipes extending from roof leaders or via connections to more substantial infiltration areas.
- A removable filter with a screened bottom should be installed in the roof leader below the surcharge pipe in order to screen out leaves and other debris.
- Adequate inspection and maintenance access to the well should be provided. Observation wells not only provide the necessary access to the well, but they also provide a conduit through which removal of stored runoff can be accomplished in a failed system.
- Though roofs are generally not a significant source of runoff pollution, they can still be a source of particulates and organic matter, as well as sediment and debris during construction. Measures such as roof gutter guards, roof leader clean-out with sump, or an intermediate sump box can provide pretreatment for dry wells by minimizing the amount of sediment and other particulates that may enter it. The need for dry well pretreatment must be determined based on site specific conditions.
Figure 1: Typical Schematic of a Dry Well

Figure 2: Typical Schematic of a Dry Well with a Possible Method for Pretreatment

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1 Pennsylvania Stormwater BMP Manual, December 2006
2 New Jersey Stormwater BMP Manual, February 2004
Appendix B

Recommendation for Infiltration Testing Procedures
For development sites where stormwater infiltration devices are proposed, soil testing is required. The purpose of the testing is to determine the potential for infiltration on the site, optimal locations for infiltration devices, and to inform final design of the infiltration devices. As one of the subtasks of the Zone 5 and 6 Storm Drain Master Planning effort, Schaaf & Wheeler is tasked to provide the County of Santa Cruz with recommendations for Infiltration Testing Procedures. All infiltration testing should be performed in saturated soil conditions, at the location of proposed BMP/LID facility. The typical infiltration tests for the design of wastewater soil adsorption fields, which are generally conducted in the dry, are not recommended for design of stormwater infiltration systems.

The County has specifically requested that Schaaf & Wheeler provide infiltration test recommendations for six scenarios: (1) bottom surface testing, (2) side wall testing, (3) falling head, (4) constant head, and for (5) shallow vs. (6) deep test locations. The recommended testing procedures for these scenarios are provided below.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Testing Procedure Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom Surface Testing</td>
<td>See below</td>
</tr>
<tr>
<td>Side Wall Testing</td>
<td>Not Recommended</td>
</tr>
<tr>
<td>Falling Head, Shallow</td>
<td>Pilot Infiltration Test or Borehole Test</td>
</tr>
<tr>
<td>Falling Head, Deep</td>
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* Schaaf & Wheeler has not identified an established alternative testing procedure for constant head testing at deep elevations, however an experienced geotechnical engineer may provide modifications to a borehole test procedure to conduct constant head testing if necessary.

Each of these scenarios is discussed, with references to specific procedures, below.

**General Recommendations**

Testing should be conducted or observed by a qualified professional. A Qualified professional includes registered professional engineers, soil scientist, geologist, architect, landscape architect, professional testing service with specific training and/or experience in determining the permeability of soils, or others as approved by the County. The County should consider including reference to ASTM D3740-12a, which provides standard practice minimum requirements for agencies engaged in testing and/or inspection of soil used in engineering design and construction, when providing infiltration testing procedures.

**Side Wall / Bottom Surface Percolation Testing**

Based on comments received from County staff, our understanding is that the County wishes to develop a separate test procedure to account for lateral flow in the side slopes or walls of infiltrations devices. Schaaf & Wheeler does not recommend this approach. Often, side slopes of large retention or detention facilities are maintained differently than the bottom surface (usually to account for vegetation). As such, it may not always be appropriate to allow for 'credit' of infiltration along side slopes or walls. For cases where the County desires to allow credit for infiltration along the side walls or slopes of a facility, we recommend utilizing the testing procedures recommended herein based on the depth and anticipated material of the testing site, and that the vertical percolation rate found based on these tests be applied at the sides walls for which credit is allowed. The pilot infiltration test procedures (described below) recommended by Schaaf & Wheeler account for side wall infiltration in addition to bottom surface infiltration.

For those infiltration tests which only measure vertical infiltration, utilizing the vertical percolation rates to account for percolation along side slopes or walls (assuming those side surfaces are maintained appropriately) is a reasonable approach, and requiring two different tests for a single infiltration device (one to establish bottom vertical percolation rate and a different test to determine lateral percolation rates) is in our opinion needlessly complex and expensive.

To allow credit for side wall percolation, Schaaf & Wheeler recommends that the appropriate test (based on depth of test and anticipated material, as recommended elsewhere in this report) be conducted at intervals along the side wall. Interval recommendations are below:
• For depths less than 10 vertical feet, one test should be performed at the mid-way elevation of the proposed side wall or slope.

• For depths greater than 10 feet, tests should be conducted at multiple elevations such that there is no more than 5 vertical feet between test locations.

The side wall should then be divided into zones of infiltration rates based on the test locations, and the total infiltration rate for the wide wall calculated based on the anticipated water surface elevation and these zones, not on averaging all tests for the entire side wall. If dramatically different infiltration rates (+/- 50%) are found at different locations along the side slope or wall, additional tests should be conducted to confirm the finding, and an unsteady analysis may be required to accurately capture the operation of the infiltration device.

**Pilot Infiltration Test**

The Pilot Infiltration Test (PIT) method is fully described in the Washington State Department of Ecology Stormwater Management Manuel, V5, February, 2005, Appendix V-B, attached. Independent review of in-situ infiltration testing and correlation of hydraulic conductivity in California concludes that the PIT is currently the most rigorous method for performing in-situ infiltration tests (Philips, 2011). The PIT procedure involves excavating a large test pit with the bottom located at the proposed elevation of the infiltration facility (or a minimum of 5 feet below proposed finished grade for permeable pavements), and conducting both constant head and falling head measurements over the course of 1-2 days. The PIT provides the most accurate infiltration estimates for a given site, includes both constant and falling head analysis and can be conducted for shallow or deep infiltration facilities. As such, Schaaf & Wheeler recommends this as a general test that fulfills all of the scenario criteria requested by the County.

However, conducting a PIT may be expensive, particularly for deep infiltration facilities. Even relatively shallow elevations likely require the use of a backhoe. As such, Schaaf & Wheeler has provided alternative recommendations herein; however note that the PIT procedure is recommended for any large infiltration facilities, particularly those that rely on infiltration for flood flow management / mitigation.

**Borehole Infiltration Test**

The borehole infiltration test is a falling head test that can be performed in shallow or deep scenarios. Schaaf & Wheeler recommends use of borehole infiltration testing procedures provided by Caltrans, California Test 750, 1986, attached, although other borehole testing methodology (i.e. EPA, 1980, County of San Bernadino, 1992) is comparable and would also be appropriate for use. All borehole infiltration testing procedures call for utilizing a 6-inch to 12-
inch auger (hand or drill rig may be used), a base layer (i.e. pea gravel or similar), pre-soaking of the soil and measurement of the decreased water level over a period of time.

While not as accurate as the PIT procedure due to the limited soil saturated and tested the borehole test is straightforward to perform, can be performed at a variety of depths, and can be inexpensive and efficient to perform. For infiltration testing in locations where PIT is infeasible, Schaaf & Wheeler recommends the borehole infiltration testing procedures outlined in Caltrans California Test 750 be utilized.

**Double Ring Infiltrometer Test (ASTM D3385-3)**

The double ring infiltrometer test as outlined in ASMT D3385-3, attached, is a falling head test that is only feasible to conduct at relatively shallow elevations. While a very common test for establishing infiltration rates, the double ring infiltrometer test was originally developed for fine-grained soils with relatively low infiltration rates. This is often the case in Santa Cruz County, and as such the test is recommended as an alternative to PIT and borehole infiltration testing, however it should be noted that rigorous attention to detail and a high level of experience with the test are required for accurate results in coarse-grained soils.

**REFERENCES**

California Department of Transportation (Caltrans), 1986 “Method for Determining the Percolation Rate of Soils Using a 6-inch Diameter Test Hole”.

