

# **Chapter 15**

## **Miscellaneous Products and Applications Using Lightweight Aggregate**

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### **15.7 References**

<b>Appendix 15A</b>	ASTM D 5268 “ <i>Standard Specification for Topsoil Used for Landscaping Purposes</i> ”.
<b>Appendix 15B</b>	ASTM D 5883 “ <i>Standard Guide for Use of Rotary Kiln Produced Expanded shale, Clay or Slate (ESCS) as a Mineral Amendment in Topsoil Used for Landscaping and Related Purposes</i> ”.
<b>Appendix 15C</b>	“ <i>Horticulture Applications for Lightweight Aggregate</i> ”, C. Friedrich, RLA, ASLA, Midyear 2000 ESCSI Meeting at Boulder, CO.
<b>Appendix 15D</b>	“ <i>Dissolved Phosphorus Retention of Light-Weight Expanded Shale and Masonry Sand Used in Subsurface Flow Treatment Wetlands</i> ”, Forbes M.G., Dickson K.R., Golden T.D., Hudak P. and Doyle R.D. (2004) Environ. Sci. Technol. 38:892-898
<b>Appendix 15E</b>	“ <i>Introducing the Friendly material: Rotary Kiln Produced Lightweight Soil Conditioner</i> ”, ESCSI Publication #8600 August 2002.
<b>Appendix 15F</b>	“ <i>Amending Soils for Turf</i> ”, ESCSI Publication 8620
<b>Appendix 15G</b>	“ <i>GreenRoofs</i> ”, ESCSI Publication #8621
<b>Appendix 15H</b>	Concrete Pipe News October 1974 “Double Barrel Pipe”
<b>Appendix 15I</b>	“ <i>Summary of Preliminary Experiments Performed to Examine “FLAIR: Fine lightweight Aggregates as Internal Reservoirs for the Delivery of Chemical Admixtures</i> ”, Bentz D.

## 15.0 Introduction

ESCS is a lightweight, ceramic material produced by expanding and vitrifying select shale's, clays and slates in a rotary kiln. The process produces high quality ceramic aggregate that is structurally strong, physically stable, durable, environmentally inert, light in weight, and highly insulative. It is a non-toxic, absorptive aggregate that is dimensionally stable and will not degrade over time.

ESCS a comparison to other aggregates: Natural sand and soil are heavy. They frequently require that structural modifications be made to the project's design. Native soils have silts and clays that may clog the filter materials or drainage layer and reduce effectiveness. The physical properties of natural volcanic aggregates vary widely wit source and location. Natural materials may degrade and compact over time, and require additions to or replacement of planting media. Some horticultural products used in greenhouses and container planting, such as vermiculite and perlite, are extremely light in weight and do not offer adequate anchorage and support for larger plants. In exterior applications vermiculite and perlite often float to the top of the planting media where they can be carried away by wind or water.

Weight reduction and product performance are the primary reason ESCS is so versatile and used in so many different applications:

- Weight reduction is very beneficial in lowering shipping cost and reducing dead loads.
- Shipping: Almost all construction products are shipped therefore, TO BUILD IS TO TRANSPORT. As an example of the money saving, truck reducing available when using ESCS see Table 15.1.



**Table 15.1. Analysis of shipping costs of low-density concrete products (Courtesy of Big River Industries).**

	Project Example Number 1	Project Example Number 2
Shipping Cost per Truck Load	\$1,100	\$1,339
<u>Number of Loads Required</u>		
Normalweight	431	87
Lightweight	<u>287</u>	<u>66</u>
Reduction in Truck Loads:	144	21
<u>Transportation Savings</u>		
Shipping Cost per load	\$1,100	\$1,339
Reduction in Truck Loads	<u>x 144</u>	<u>x 21</u>
Transportation Savings:	\$158,400	<u>\$28,119</u>
<u>Profit Impact</u>		
Transportation Savings	\$158,400	\$28,119
Less: Premium Cost of LWC	<u>17,245</u>	<u>3,799</u>
Increase in Gross Margin	<b>\$141,155</b>	<b>\$24,320</b>

- Dead Load Reduction – Dead load reduction becomes very important in roof top gardens and other elevated applications as well as when unstable soil conditions exist.
- Thermo-Structural Stability – Because of the extremely high temperature (approx 2,000°F) used in the firing production of ESCS, these aggregates have in effect been proof tested thus providing resistance to the thermal shock experienced in commercial refractory or consumer products, such as gas grill, briquettes, fireplace logs, fire box liners, etc.
- An accessible system of pores. A large volume of accessible pores provides a vehicle for absorption, storage and then desorption of water or solutions containing admixtures. This includes rainwater in gardens, and as a carrier of solutions containing chemical admixtures, herbicide and fertilizer.
- Water resisting consumer products. The proven resistance to the degrading effects of wetting/drying makes ESCS as a valuable component of wallboard, roof tiles, and artificial stone.
- Product Durability – ESCS is a strong, durable lightweight ceramic material that will not degrade over time.

#### Horticulture Applications

- Soil Amendment Principals
- Green Roofs
- Structural Soils
- Potting Soils
- Hydroponics
- Herbicide Delivery

#### Environmental Medium Applications

- Septic Drainfields
- Self Contained Urban Storm Water Systems
- Recirculating Filters
- Wetlands Improvements

#### Manufactured Consumer Concrete Products

- Cement Wallboard
- Artificial Stone
- Concrete Roof Tiles
- Fireplace Logs, Boxes and Chimney Liners

#### Sports Field Applications

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#### Surface Applications

- Architectural Ground Cover
- Sub-Surface Insulating Loose LWA Fill
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#### Specialized Non-Structural Concretes

- Roof Fill (Insulation and Slope to Drain)
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- Shotcrete
- Flair (Fine Lightweight Aggregate Internal Reservoirs-Admix DLYY system)
- Insulation of Radiant Heated Floors

Because of these unique properties ESCS aggregates have a long history of applications that are outside of the traditional uses; masonry, structures, asphalt and geotechnical. Some of these diverse applications are listed below:

## 15.1 Horticulture Applications

### Soil Amendments Principals

All healthy turf has one thing in common: *a good root system*. Roots that can move through the soil freely help grass plants establish and recover more quickly than those that are placed in compacted and poorly drained soils. Compacted soils force roots to grow very near the soil surface. This greatly reduces drought

resistance and increases the possibility of diseases from poor drainage. It is generally understood that to achieve healthy turf, it may be necessary to amend soils with materials that promote strong root development.

Properly amended solids will yield strong, healthy turf that requires less maintenance. It not only protects your investment, it enhances it.

Soil is a fragile growing medium consisting of three components: solid particles, water and air. It is necessary to maintain a careful balance of these elements to establish a good soil profile.

Generally speaking, a good soil profile is approximately 25% water, 25% air, and 50% solid particulate matter. However, when solid are compacted the profile becomes unbalanced as a result of changes in the soil structure. Solid particles are pressed together eliminating space for the water and air. With less pore space, soils become too dense for the movement of water and for the exchange of air and nutrients. With this compacted solid condition, the favorable environment for the beneficial microbial activity necessary for a healthy growing medium is lost.

Soils are not generic in structure, so why should the methods of conditioning them be? By providing adequate drainage, reducing nutrient loss, improving moisture retention, enhancing soil resiliency, and increasing resistance to compacting, a balanced solid can be achieved. Organic amendments are essential for healthy balanced solids, but they absorb water and without adequate air and drainage can contribute to the growth of harmful fungi and bacteria. Historically gardeners added grit or sand to the soil to help aerate it. However, over time the soil becomes compacted around these solid particles, the pore space is reduced, and the air supply to the roots is cut off.



**Figure 15.1** *ESCS can provide an essentially Permanent, single application solution*

Lightweight Expanded Shale, Clay and Slate (ESCS) soil conditioner is playing a new and valuable role in today's horticulture. Produced by firing shale, clay or slate in a rotary kiln at temperatures in excess of 2000°F this fully calcined, ceramic material offers superior solutions of many of today's horticulture problems and application. Some of the applications for ESCS are listed below:

- Planting for green roofs and roof top gardens
- Golf course green and tee construction and maintenance.
- School and institutional turf and plant areas with high use and compaction problems.
- Where well-drained surface areas are necessary; such as baseball in-fields, football and soccer fields, non-paved concession stand areas, parking areas and walkway.
- For decorative mulch or ground cover.
- As a soil amendment for potting soil or greenhouse plantings.
- In problem soils with poor drainage it provides better aeration and keeps soil open.
- In soils or planting areas which tend to dry too rapidly or cake; i.e. hillsides, extremely well-drained areas, adobe soil, clays, etc. ESCS has the ability to retain moisture in each particle at the root line.
- In potting soil and greenhouse planting and maintenance.

- As an extender of liquid fertilizers and chemicals.
- Structural soil for urban trees and fire lanes.

The following physical property characteristics explain why ESCS LWA performs very well in many varied soil conditioner applications listed above.

- Non-toxic
- 100% inert
- Strong, durable and long-time stability
- Insulates
- Acts as an environmental buffer by moisture exchange
- Provides for soil aeration, non-compactions
- Less weight on structural frame

A comprehensive summary of horticulture applications for lightweight aggregate was presented by Chuck Friedrich RLA, ASLA of the Carolina Stalite Company at the April 30, 2000 ESCSI midyear meeting at Boulder, Co. This presentation thoroughly covered:

- Amending heavy compacted soil
- Structural soil for new urban trees and turf
- Structural bridging over existing tree roots
- Lightweight roof garden soil mix

Numerous examples of successful completion of major architectural projects are described. This work is enclosed as Appendix 15C.

## **Green Roofs**

ESCS has a long history of success in horticultural applications all over the world. It is marketed under various trade names and has established itself as the standard for creating planting media for rooftop gardens. This track record of proven performance demonstrates how ESCS, at about 50% of the weight of natural planting media, contributes to sustainable development by conserving energy, reducing trucking requirements and minimizing the impact on structures.

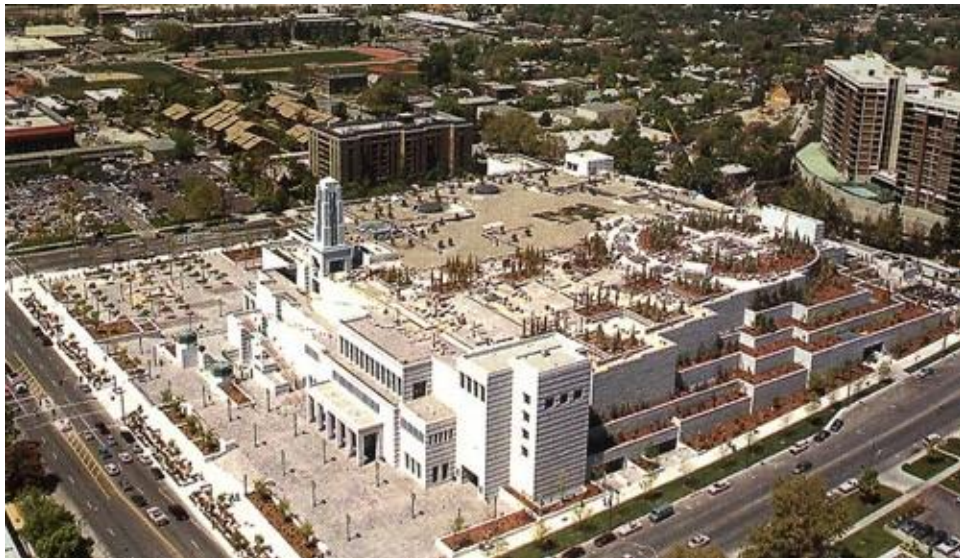
The use of this environmentally friendly ceramic material in greenroof design helps address important issues such as managing storm water runoff, improving water quality, reducing urban heat, conserving energy, lowering dead load and increasing green space.

One of the most important components to both extensive and intensive greenroof systems is a quality planting medium. Because of the complex nature of greenroof construction and the difficulties of access after completion, the planting media must be able to support and sustain plants for the duration of the intended life span of the roof. A well-designed planting medium will have the following physical characteristics:

- Be free of silts and clays that could clog the filter fabric;
- Have permanent internal aeration even after several years of consolidation;
- Insure adequate drainage;
- Insure stable root support;
- Not degrade, breakdown or shrink in volume over time.

ESCS is the environmentally friendly answer that provides a long-term solution to the above complex design requirements.

Besides exceeding all the requirements of an ideal planting medium, ESCS provides additional important benefits. Its reduced weight can often accommodate structural design requirements; yet it is heavy enough to avoid loss caused by excessive wind or water. Some ESCS are spherical, its open grading, stable and porous ceramic nature ensures an adequate supply of air to enable plants to be established quickly and develop healthy root systems. Ample aeration increases the insulative properties of the planting media and helps reduce energy consumption as well as lessen the urban heat island effect. Overall project costs are often reduced because ESCS can also serve as the drainage portion of the greenroof system. When used for storm water management, the porous planting medium allows rain water to readily penetrate the soil surface. This reduces runoff and allows pollutants to be naturally filtered and remediated thereby improving water quality.



**Figure 15.2 7-acre rooftop garden atop  
LDS Conference Center in Salt Lake City, Utah.**





**Figure 15.3** *Perimeter planting on roof of  
LDS Conference Center in Salt Lake City, Utah.*



**Figure 15.4** *Extensive greenroof garden,  
City Hall, Atlanta, GA. 2004*

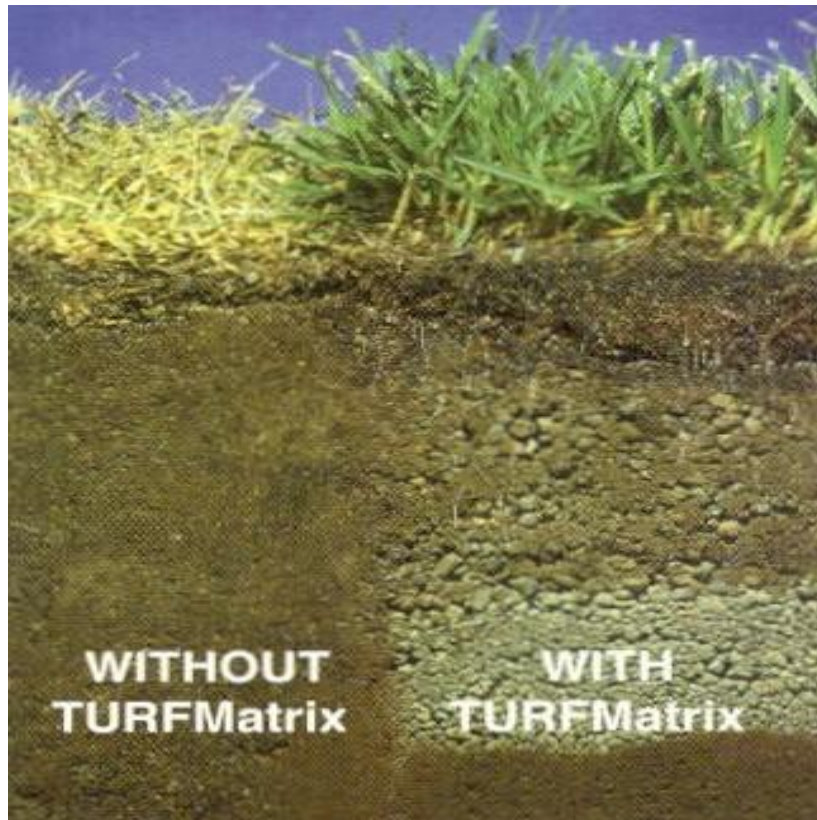


**Figure 15.5** *SOILMatrix installed by blowing equipment atop six-story Atlanta City Hall*

### **Structural Soils**

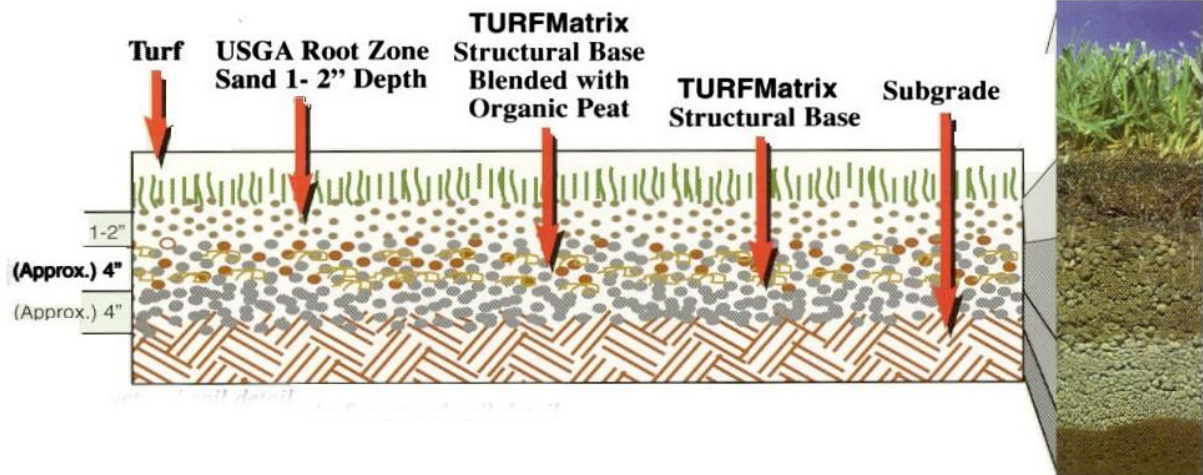
Typically lawns do not recover quickly from compaction by vehicles or heavy foot traffic. Many building codes now require fire lanes that will allow access by heavy fire trucks to the edges of buildings. Often only paving or block-reinforced turf is accepted for this application. ESCS structural soil, which by volume is a mixture of 3 parts TURFMatrix (3/8" to 1/4" graded ceramic particles) to one part sandy loam with 5% organic matter content, meets the support requirements for fire lanes.





**Figure 15.6** *Soil with and without  
TURFMatrix structural soil*

The purpose of ESCS structural soil is to provide a stable root zone that will sustain a quality lawn while assuring support for emergency vehicles when necessary. It will also support periodic vehicular parking or heavy foot traffic between recovery periods. Continuous vehicular use of the lawn requires the application of plastic support rings in addition to the structural ESCS.



**Figure 15.7 ESCS Structural soil detail**

Structural soil construction Fig 15.6 and 15.7. After the subgrade is uniformly compacted to 95% of its maximum dry density, the 3/8" to 1/4" – size ESCS can be placed in uniform lifts over the entire area, and compacted (using a vibratory plate compactor) to provide a finished depth of about 8". A blend of ESCS and organic peat is often used to create the upper half of this compacted layer as shown in Fig. 15.7. A 1" to 2" layer of USGA root zone mix is then placed on top of the compacted ESCS. It is now ready for seed or a sand-based sod. If the subgrade is impervious to water, a drainage system may be required. Once the turf is established, the system will support a quality lawn, and, in the event of an emergency, a fire truck, crane or other heavy equipment.

### **Hydroponics and Potting Soils**

ESCS has a more than 25 year record of providing an excellent medium for all types of hydroponics and potting soil applications. ESCS particles can be graded to provide an optimum environment allowing an ideal balance of moisture, food and air.

Because of the control of the manufacturing process ESCS can be optimally graded delivering predictable voids between the particles allows much needed oxygen to reach the roots, minimizing or eliminating the possibility of root rot.

Because ESCS has been fired at temperatures of 2000°F, the particles are sterile, odorless, and non-allergenic so there are no soil-related diseases or pests. ESCS particles do not decompose, emit no toxic substances into the nutrient solution and will not support bacteria or fungus growth. Because of its inherent inorganic porosity, it is extremely lightweight compared to soil.

There have been many experiments and reports of the successful use of ESCS in hydroponic applications of which the following is typical.

“Greenhouse experiments are underway using 5/16 + #8 expanded shale as a base. Soil is not used. Roses and carnations are being grown by a modified hydroponic system. The word “modified” is used because in a normal hydroponic system beds are flooded and excess water is reclaimed and re-used. In this modified system, the nutrients are metered into the water, but only sufficient total water is sprayed to saturate the aggregate. Very little, if any, water flows from the beds therefore, a reclaim system is not required. The roses were planted May 9, 1966 and were watered every four hours for approximately two months. They are now watered for one minute at 8am and for on minute at noon each day. On October 25 these roses were at least five feet tall, with extremely long stems, and have developed beautiful firm blooms which are uniform in color” (Idealite Co. Tom Brown).

“Carnations grew tall and matured approximately fifteen days ahead of normal soil carnations. A minor amount of calcium available to the plants has been helpful in that the tall stems are not brittle. These carnations could be shipped to Europe with no stem problem. Competitive non-soil plots with no calcium available are very brittle, which would generate a shipping problem to a local florist.”



**Figure 15.8** *Sedum* growing in ESCS at Sauls Nursery



## Herbicide Delivery

ESCS is a porous, durable ceramic aggregate. ESCS permits absorption of solutions containing chemicals, both for herbicides and chemical admixtures for concrete applications. The slow release of the chemical in solutions from the pores of ESCS permits a gradual supply of the ingredient thus minimizing an excessive interaction with the treated material (soil or concrete).

## 15.2 Environmental Medium Applications

### Introduction

ESCS has been produced to special and in some cases, unique gradings to meet the requirements of septic drain fields, sewerage sand filters and exfiltration. Because of its durable, acid resistant, vitreous mineralogy it has proven performance of a long service life in aggressive environments.

- **Mineralogy:** ESCS structural lightweight aggregates are mainly composed of vitreous amorphous alumina-silicates. ESCS is environmentally inert, non-toxic and extremely durable. Broken shards of its ceramic cousin, pottery used in the construction of piers in Cosa, Italy over 2000 years ago are still in place today.
- **Density:** Because the bulk density of ESCS is less than ½ that of ordinary aggregates, the tonnage shipped and placed is reduced. Additionally, the installation and cleaning labor costs will be lowered.
- **Product Control:** Because of product controls, ESCS may be purposely graded to specified effective size and uniformity coefficients, permitting an increase in void space. Increased void space will be conducive to effective drainage and increased service life.
- **Particle shape and texture:** ESCS aggregate surface is irregular, rough, porous, and absorptive thus providing a large aerated surface for friendly microbial action to thrive. The rough micro surface texture also helps keep an effective void space between particles.

**Septic Drain Fields:** In a number of geographical areas the locally available natural aggregate has a calcium based mineralogy i.e. limestone and dolomite. Over time the calcium is attacked by the acid component of the effluent and tends to lose permeability due to cementation, leading to reduced performance or failure.

In some areas, Florida for example, structural lightweight aggregate (ESCS) has been successfully used in septic tank drain fields for over 30 years. Although the aggregate has a higher first cost, the long-term service life and lower maintenance has proven to be more economical.

In order to compare the acid resistance of a limestone and two ESCS aggregates, a series of tests were conducted in a fashion paralleling ASTM C 88 “*Standard Test Method for Soundness of Aggregates by use of Sodium Sulfate or Magnesium Sulfate*”. To accelerate the test a 32% solution of hydrochloride acid was used with weight loss checked periodically. The limestone clearly softened, lost weight and tended toward a cementation state. The ESCS LWA was visibly unchanged with a weight loss that was primarily the result of repeated mechanical screenings. The weight loss of the limestone sample was 6.47 times that of the ESCS sample. A copy of the test procedure follows with the test results shown in Table 15.3.

In order to provide a comparison of the drain field acid resistance of several aggregate, a non-standard test procedure similar to ASTM C 88 was adopted.

<u>Sample Marking</u>	<u>Lab #</u>	<u>Material</u>
VD	M1134	ESCS LW Aggregate (V)
FA	M1134	ESCS LW Aggregate (F)
LD	M1134	Oolitic Limestone

**Table 15.2. Test Results of Acid Resistance of ESCS & Limestone Aggregates**

Sample	Initial Wt., Gms.	(Sieve Size) # of Pieces	Final Wt., Gms.	(Sieve Size) # of Pieces	% Loss by Wt.
VD	156.7 (1/2")	57	153.6 (1/2")	57	1.99
	156.3 (3/8")	137	149.7 (3.8")	137	4.22
FA	304.5 (1/2")	85	292.2	85	4.10
LD	397.9 (1" & 3/4")	29	289.8	29	27.2
	397.4 (1/2")	55	328.5	55	17.3

The loss noted with samples VD & FA appeared related to small particles breaking off during the final sieving. The loss of the LD material was the result of reaction of the aggregate with the acid.

Testing Procedure:

1. Prepare samples per ASTM C 88 – wash, dry, separate into various sieve sizes.
2. Weight equal (approximate) quantities of each sieve size for each sample. Count number of pieces.

3. Place each quantity of aggregate in plastic container (container must have positive snap lid) add cover with 32% solution of hydrochloric acid.
4. Place on level surface in sealed container for 4 weeks. Do no disturb during this period.
5. After 4 weeks examine aggregate for deterioration.
6. I major loss has occurred pour off solution and wash remaining aggregate. Dry and sieve over next smaller screen.
- 6.a If no loss is noted reseal container and store, check every 2 weeks. When major loss is noted follow procedures 6 and 7.
7. Record weight and number of pieces retained. Calculate percent retained by weight and number.

Thousands of septic tank drainfields have been used in Florida for more than four decades. No failures due to lack of performance of the ESCS aggregate have been reported, thus minimizing warranty work. With ESCS bulk loose densities less than 1200 pcy, compared to usual aggregates weighing more than 2500 pcy, contractors are able to carry much more aggregate on their trucks with fewer stops required. Construction workers like ESCS because of its lower weight and ease in spreading in the drainfield.



**Figure 15.8** *Installing ESCS in septic tank  
Drainfield in Florida.*

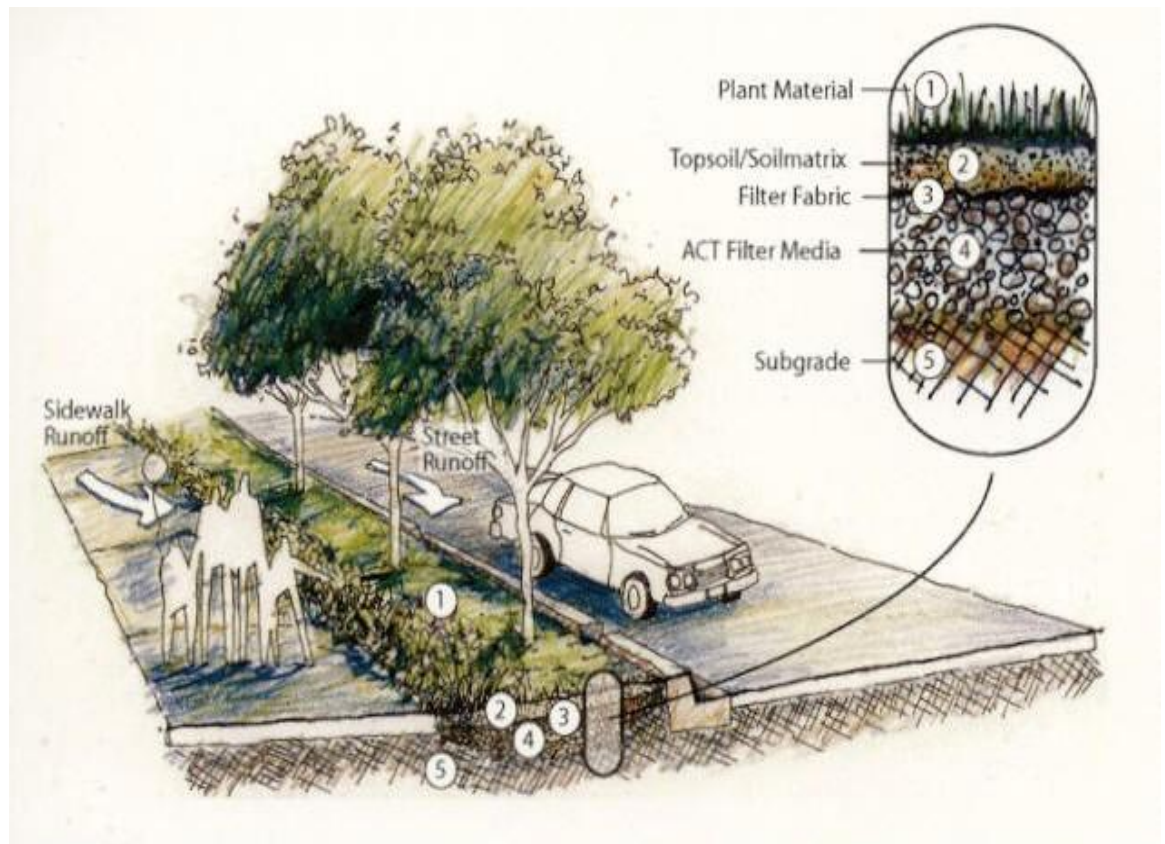
## Self Contained Urban Storm Water Systems

(The following information is excerpted from the ES Filter brochure “ACT Filtering Media, Cleaning Waste Water with ACT Filtering Media, Ogden, Utah)

The following are four environmentally friendly solutions to urban storm water runoff:

1. Bioswales
2. Filterstrips
3. Rain Gardens
4. Rain basins

These biofiltration systems may be used for both point source and diffuse storm water. They treat water on site, offer aesthetic, financial, educational and ecological benefits. Though a fairly new design concept, self contained urban storm water systems show an initial cost comparison that indicates an apposite cost to benefit ratio. These systems give the designer the advantage of effective storm water treatment, while allowing the client the opportunity to showcase the ecological and educational benefits to the community.



**Figure 15.9 Self Contained Urban Storm Water Systems**

All of these designed systems are known to be effective in capturing solids, oils and less soluble metals. In the removal of oils, such vegetative systems have been shown to be an economical choice due to the fact that vegetation is much less

expensive than oil separators. However they have not been every effective in the treatment of more soluble metals and even less still in the case of phosphorus.

The following definitions are also excerpted from the “ACT Filtering Media Publication”.

Bioswale is a term coined for a linear drainage channel, planted with the appropriate vegetation for the bioremediations of pollutants from urban storm water runoff. Best suited to treat runoff that has been collected and concentrated, such as the outfall to a peak rate runoff control facility, water flow at a shallow depth and at a relatively slow velocity through vegetation but generally has very little or no ground infiltration.

Filter strips are generally defined as areas of vegetation over which dispersed runoff sheets flow at a very shallow depth. Filter strips are very well suited to treat runoff from impervious areas such as parking lots and may be designed into the overall landscape as parking area islands or edge borders.

Rain gardens, unlike a bioswale, are designed to retain water and allow infiltration. Water is cleansed by vegetation and by simple soil systems filtration.

Rain basins have been gaining in popularity and may be placed beneath parking areas to make the most efficient use of the property. Used as an integral part of the storm water management design, runoff water is collected, cleansed and allowed to infiltrate into the ground to help aquifers and reduce or eliminate storm water runoff into the municipal system.

### **Recirculating Filters**

Under the direction of Rich Piluk, Maryland Anne Arundel County Health Department has pioneered the use of re-circulating filters for the treatment of wastewater from individual homes. According to Piluk these small re-circulating filters can produce a high quality effluent and even remove approximately 70% of the total nitrogen in the septic tank effluent. Experimentation with the use of ESCS aggregates has shown that similar treatment can be achieved with expanded aggregates.

Anne Arundel County has also substituted ESCS for natural aggregates in septic drainfields and beds. This application uses larger quantities of ESCS than in re-circulating filters. In the drainfields is placed a network of drip tubing that distributes the wastewater in the ESCS bed. Piluk reports that the experience with this type of system has been very favorable, no clogging around the drip emitters has been observed. Limited sampling indicates that this system is capable of producing an extremely high quality effluent



## Stormwater Exfiltration Trenches

In some localities governmental agencies have upgraded storm water runoff collection requirements. When the cost of real estate is high, exfiltration trenches may prove to be an economical alternative to retention ponds. Retention ponds require continuous maintenance, have a need for security fences and may be a breeding area for insects.

Using run off coefficients that may be high in built-up land areas, engineers can compute the necessary volume of voids that will accommodate the amount of water produced in a specified intensity of rain. Considering the area, length and the available voids in the aggregate the trench dimensions may be determined. In some areas ESCS LWA that although more costly initially, have been shown to be more economical than ordinary stone and gravels, because the ESCS was deliberately graded to a high void content (The exact opposite of concrete technology where aggregates are graded for minimum void content). The pore space in the aggregate is also available, but this should be considered an undefined additional safety factor. The savings result from the lower construction costs of a smaller trench.

## Subsurface Flow Treatment Wetlands

A paper titled “*Dissolved Phosphorus Retention of Lightweight Expanded Shale and Masonry Sand Used in Subsurface Flow Treatment Wetlands*”, by Dr. M. Forbes was at the ESCSI Midyear meeting in Baltimore, MD, May 2004 and reported that ESCS could provide a suitable substrate for the retention of phosphorus (Appendix 15D). The physical properties for ESCS and the masonry sand used for comparison are shown in Table 15.4.

**Table 15.3. Physical Characteristics of Masonry Sand and Expanded Shale**

Characteristic	Masonry Sand	Expanded Shale
Effective sizes ( $D_{10}$ ) unit	110	720
Uniformity coefficient	1.4	2.3
Density ( $\text{kg/m}^3$ )	1870	728
Porosity (n)	0.304	0.594
Hydraulic conductivity (k) (m/d)	17.3	92.2
pH of 10 g of material in 50 ml of water	8.28	9.38

The following excerpts from Dr. Forbes’ paper are noteworthy.

“Slower, prolonged P (Phosphorous) by expanded shale may be associated with chemical and physical sorption to less excessive sites located within the micro pores of this porous material. Longer term sorption may also be a function of diffusion of P into the interior of the particle. As pH decreased in column and pilot studies, reactions with hydrous oxides of Al + Fe would be favored, and

formation of Al – P as well as Fe – P compounds may contribute to the long term P retention in expanded shale columns and pilot cells. Releases of previously sorbed P from expanded shale were minimal in desorption experiments and were not observed in field studies....given the high Al + Fe content of this material these results are consistent with our expectations that expanded shale would provide high sorption capacity that would not be easily reversed. Other researchers (27, 28) have found that sorption capacity of materials such as zolite and light expanded clay aggregates (LECA) were closely correlated to both oxalate extractable Fe + Al.”

“Despite some reported successes with sand in subsurface flow treatment wetlands, our study found that masonry sand is a poor candidate for dissolved P retention. Its P sorption capacity as estimated by the Langmuir sorption model was only 58.8 mg/kg, compare to 971 mg/kg for the expanded shale. Masonry sand also readily desorbed P when exposed to more dilute solution in both isotherm desorption and column experiments. Some of the low P retention by masonry sand may have been due to its poor hydraulics. Although sand’s hydraulic conductivity (K) in the lab seemed adequate, when scaled up to the columns and pilot cells, flow rates were much lower and short-circuiting occurred. The aerial retention rate of expanded shale was 40 times greater than P retention reported for sedimentation and over 100 times greater than global estimate of peat accretion. We attribute this in part to the excellent hydraulic provided by expanded shale as well its high surface area and sorption affinity. By contrast, the adjacent, aged, surface flow wetland randomly exported P probably due to P saturation of sediments at the sediment-water interface. Given the high rates of soluble P retained by expanded shale in our subsurface flow pilot cells, these systems warrant further and longer term study”.

## **15.3 Manufactured consumer Concrete products**

### **Cement Wall Board**

Cementitious backer board products that incorporate ESCS have a long successful history in residential and commercial applications. Unlike products based upon gypsum, these manufactured boards are resistant to wet/dry cycles and will not soften, swell, rot or disintegrate under exposure to moisture. In addition to durability ESCS backer boards are dimensionally stable and because of their resistance to high temperature, achieve one and two hour fire resistance ratings when used with wood or steel studs.

ESCS backer board has served as a permanent, durable base for ceramic tile, thin brick, epoxy matrix stone aggregate surfacing and other exterior base coat finishes. Additionally, because of the use of structural grade lightweight aggregate these products can withstand high levels of compressive and flexural

stresses and are highly resistant to chipping of edges. Using ESCS as a constituent permits safe and easy handling by one person.

ESCS has been supplied to wallboard manufacturers by the following member companies.

**BIG RIVER INDUSTRIES, INC.**

3700 Mansell Road, Suite 250  
Alpharetta, GA 30022  
(800) 342-5483 • Fax: (678) 461-2845  
Website: [www.bigriverind.com](http://www.bigriverind.com)  
♦Livingston, AL ♦Erwinville, LA  
♦West Memphis, AR

**NORLITE CORP.**

628 S. Saratoga St.  
Cohoes, NY 12047-0694  
(800-) 322-2446 • Fax: (518) 235-0233  
Website: [www.norliteagg.com](http://www.norliteagg.com)  
♦Cohoes, NY

**DEGERONIMO AGGREGATES  
LLC**

5531 Canal Road  
Valley View, OH 44125  
(216) 524-0999 • Fax: (216) 524-9066  
♦Independence, OH

**TXI-TEXAS INDUSTRIES, INC.**

1341 W. Mockingbird Lane  
Dallas, TX 75247-4231  
(972) 647-6700 • Fax: (972) 647-3785  
Website: [www.txi.com](http://www.txi.com)  
♦Streetman, TX ♦Clodine, TX ♦Port Costa, CA  
♦Frazier Park, CA ♦Boulder, CO

**HYDRAULIC PRESS BRICK CO.**

5505 West 74<sup>th</sup> Street  
Indianapolis, IN 46268  
Email: [haydite@aol.com](mailto:haydite@aol.com)  
(317) 290-1140 • Fax: (317) 290-1071  
♦Brooklyn, IN

**Artificial Stone**

As mentioned earlier, ESCS because of its significant weight reduction is widely used to lower shipping costs of consumer type products. As shown in Table 15.1, there is a dramatic reduction in the environmental impact as reflected in the number of trucks required to transport these products into residential areas. Throughout North America there are a large number of production plants manufacturing durable, attractive, maintenance free, totally realistic, integrally colored artificial stone elements as demonstrated in Fig. 15.5. ESCS is used in this product because it reduces weight, reduces chipping and improves durability while still providing excellent color contrast and esthetic appeal.



**Figure 15.10** *Typical Artificial Stone Product manufactured Using ESCS lightweight concrete.*

### **Concrete Roof Tiles**

ESCS has been successfully used in the production of concrete residential roof tiles. As expected, this application is driven by weight reduction, durability, color availability and fire resistance considerations. In addition to significantly reducing trucking loads, there is also the consideration of allowable loads on existing framing when a residence is re-roofed.

ESCS has been supplied for use in lightweight concrete roof tile by the following manufacturers:

#### **TXI-TEXAS INDUSTRIES, INC.**

Dallas, TX

Website: [www.txi.com](http://www.txi.com)

#### **UTELITE CORP.**

Coalville, UT

Email: [Utelite@allwest.net](mailto:Utelite@allwest.net)

### **Fireplace Logs, Boxes and Chimney Liners**

Because ESCS is manufactured at temperatures above 2,000°F , the high temperature thermo-structural resistance properties of ESCS are widely used in consumer products that are exposed to repeated fires. One example of these types of products is fireplace logs (Fig. 15.8)



**Figure 15.11. *Fireplace logs***

Another similar heat resisting applications is in the manufacture of gas-grill briquettes for residential barbeques.

### **Precast Lawn & Garden Furniture and Ornaments**

The precast concrete industry has always been a major user of Rotary Kiln Aggregates. A small facet of this industry has been the Lawn & Garden Furniture and Ornaments. Many of these manufacturers are shipping to department stores and general retail outlets. A reduction of 30% in weight, will provide the opportunity for a sale of a precast ornament which previously has been too heavy. Delivery and handling damage has been greatly reduced.

## **15.4 Sports Field Applications**

### **Baseball and Field Sports**

ESCS has been used to improve the surfaces of sports fields for more than 20 years. The improvements observed by superintendents of sports fields are due to:



- The initial rapid absorption of the water by ESCS combined with the relatively slow release (desorption) allowing maintenance of the playing field.
- ESCS amended soils appear to fluff up with a nail drag between games.
- ESCS amended soils appear to decrease loss of surface due to wind erosion.
- Relatively inexpensive and totally durable, will not degrade with time, thus minimizing replacements.
- ESCS mixes easily and modifies top dressing soils
- ESCS is unaffected by field maintenance chemicals
- Infield sprinkling may be completed almost up to playing time.

For most top dressing soils used on fields, apply an average of 20 cubic yards of ESCS uniformly to the skinned infield of a baseball field about one inch deep. Softball fields usually require more quantity, since they have larger skinned areas. The infield conditioner is next roto-tilled into the top three inches of soil. Exceptions would include treating a lean clay field. Additional ESCS must be tilled in to lean clays. After tilling, use a roller to compact the blend.

For all the details on purchasing, transportation and installation, calls should be directed towards local ESCS manufacturers. A complete list of manufacturers can be found at [www.escsi.org](http://www.escsi.org) under ESCSI members.

## **Running Tracks**

For more than forty years ESCS aggregates have been used for running tracks.

A 440-yard track will require from about 350 to 3,000 cubic yards of aggregate, depending upon the number of lanes, the length of the straight-away, the standards (High School to Olympic), and the courses using the aggregate.

The surface course is usually 3 to 4 inches in depth, and the base courses range from 6 to 8 or 24-inches in depth. The sub-base of 6-inches is generally gravel or crushed stone, but apparently some ESCS producers have furnished material for this course also. The base has large yardage and 3/4" to #4 materials seems to do a good job. For High School tracks, this course is 5 to 6 inches and for College and Olympic tracks it is 18 to 24 inches.

The surface or topping course is a blend of #4 to 0 aggregate and a clay binder. The blending is such as to result in a plasticity index of 2 to 5%. The blending may be done in place with usual equipment, or it may be done in a ready-mix truck.

The following are excerpts from two specifications for the topping course that ESCSI members have sent us.

**California, 1954:** The top three (3) inches shall be constructed with Haydite [ESCS] aggregate graded from one-fourth (1/4) inch to twenty (20) mesh mixed in proportions by volume of one (1) part Haydite to one (1) to one and one-half (1 ½ ) parts sandy-clay soil, which has previously been screened through a one-fourth (1/4) inch screen, to remove all lumps or oversize material. The Haydite aggregate and the soil shall be mixed in a concrete mixer until an even blend of the two (2) materials has been attained. This material shall be screeded, lightly sprinkled and rolled with a hand roller weighing not less than 500 pounds. Should depressions appear after initial rolling, the surface shall be lightly raked, additional material applied and screeded and rolled. This procedure shall be followed until the surface is even between top of header boards, well compacted and true to surface grade.

**Georgia, 1968:** Finish Course: 6" expanded shale volumetric blend 50-50 3/8" - #8 and 3/16" – 0 mixed with about 15- 20% by volume of clay from project site. Compacted again with same equipment.

In 1958-62 Cedric Willson prepared some notes and typical specifications for Running Tracks and discussed this market at one of our Annual meetings. A modification of his copy suggested specifications as follows:

The following specifications are suggested for the construction of a high-grade running track:

Materials: All aggregate for surface and base courses of running track shall be rotary kiln produced ESCS complying with the requirements of ASTM Designation C 330 "Lightweight Aggregate for Structural Concrete", except for gradings which shall comply with Sections 2, 3 and 4 of these specifications. Surface and base courses for the track shall be all of one type of aggregate and the use of different types cinders for the construction of one track shall not be permitted.

Base Course : ESCS for base course shall comply with the following grading:

<u>Screen size (square openings)</u>	<u>Percent passing</u>
2"	100
1"	90-100
1/2"	25-60
1/4"	0-10

Intermediate course : ESCS for intermediate course shall comply with the following gradation:

1/2"	100
3/8"	80-100
#4	5-40
#8	0-20

Surface course: ESCS for surface course shall comply with the following gradation:

#4	85-100
#8	40-80

Construction of base course: The subgrade shall be prepared by grading and rolling to a uniformly compacted surface in accordance with elevations and cross-section as shown on plans. Base course cinders shall be spread uniformly on the sub-grade to a compacted depth of \_\_\_\_inches. After spreading, the base course, the ESCS shall be lightly sprinkled and uniformly rolled to a true cross-section with a roller having not less than sixty pounds or more than one hundred pounds weight per lineal inch of roller contact surface.

Construction of intermediate course: Intermediate course ESCS shall be spread uniformly on the base course to a compacted depth of \_\_\_\_inches. After spreading, intermediate course ESCS shall be lightly sprinkled and uniformly rolled. Roller having same specifications as in paragraph #5 above.

Construction of surface course: The contractor may elect to construct the surface course by one of the following alternate methods:

General: ESCS for surface course shall contain a clay binder uniformly and homogeneously mixed. The clay binder and surface ESCS shall be mixed dry and lumps of clay shall not be used to give a completed surface course a plasticity index of not less than 2% and not more than 5%.

Alternate method No. 1: The surface course shall consist of surface ESCS which have been uniformly and thoroughly mixed with the proper amount of clay binder. This mixture shall be spread evenly over the completed intermediate or base course so that the compacted thickness of the surface layer when rolled in accordance with paragraph 5 shall be not less than four inches.

Alternate method No. 2: Following construction of base course and intermediate course (if included), surface cinders shall be spread and compacted. The compacted surface shall be not less than four inches. The proper amount of clay binder which will develop a plasticity index of not less than 2% and not more than



5% in the surface course shall be spread on top. The clay binder shall be thoroughly and uniformly mixed into the surface cinders by using a Seaman-Andwall Pulvri-Mixer or equal type of equipment which will blend, mix and partially compact the two materials. After the clay binder has been thoroughly mixed into the surface cinders, the surface course shall be rolled. Following the initial rolling the surface course shall be lightly sprinkled and given a second rolling to a uniform surface. Roller for surface course rolling shall meet the same requirements as specified under construction of base course in paragraph 5 above.

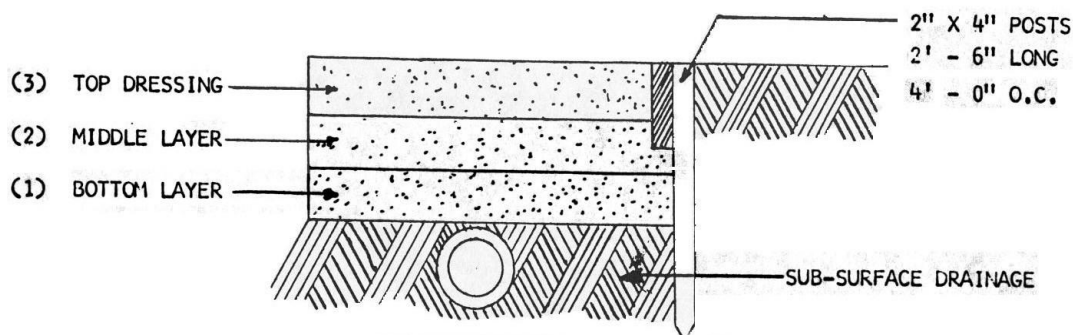
Note: Depending on the length of the straight of way approximately 120 to 150 cubic yards of clinker will be required to produce on inch depth of track.

#### Typical Running Track Project Specifications:

Bottom layer – Place 6" of #1 crushed stone on prepared subgrade taking adequate precautions not to knock the open joint pipe out of alignment or to disturb the grade. Level and roll well before placement of the middle layer. Do not roll directly over pipe.

Middle layer - Shall be 6" layer of ESCS coarse aggregate placed, leveled, and thoroughly compacted before the placing of the top layer.

Top dressing – This 6" layer shall consist of four parts of finely screened ESCS LWA to one part of clay. The LWA shall be run through a 1/4" mesh. The clay shall be very dry and broken into a powdered form prior to being thoroughly mixed with the ESCS. This mixture of LWA and clay shall be put down in 2" layers, dampened, and thoroughly compacted prior to the placement of the next layer. At the time of final inspection for the track it shall have been dampened, raked, and rolled to a smooth surface.



**Figure15.12** *Typical Cross Section*



**Figure 15.13**



**Figure 15.14** *Dietz Stadium Running Track*  
*Kingston, New York*



**Figure 15.15.** *Surface Texture of ESCS Running Track*

### **Golf Greens**

Because of its long service life and its moisture retention properties ESCS LWA has been successfully used in numerous applications on golf courses. The following literature and reports from three different locations provide the supportive information essential for understanding the vital factors for good golf course soil conditioning.

The following information adapted from various articles and trade brochures describe the application of ESCS Lightweight Aggregate to Golf courses.

**Top Dressing and Soil Conditioner:** ESCS is an organically inert material that has been finely crushed, then kiln fired and expanded. This expansion process traps thousands of microscopic air pockets within the materials, contributing two vital factors for good soil conditioning: (1) provides remarkable water absorption properties, which rapidly dissipate surface water and hold the water at root level, and (2) creates a lightweight material that is dispersed and “floats” within the soil to retain moisture, aerate the soil, and produce a flexible “lively” turf. ESCS retains its physical characteristics and soil conditioning properties indefinitely!

ESCS is perhaps the most economical and effective soil amendment and conditioner available. It is an effective aerator of heavy soils and more readily retains moisture at the root line of light soils.

A granular, mineral-based product, ESCS will not break down in the soil. It last indefinitely. Lawns, trees, ornamental growths grow and retain their beauty when soils are structurally organized to permit adequate aeration for better flow of moisture and plant nutrients. The incorporation of ESCS in the soil gives plants the proper soil structure for maximum growth. ESCS can substantially reduce the many costs of plant maintenance.

**Suggested Rate of Application:** In new soil construction for lawns, greens, tees, or plants, ESCS should be worked into the top three to six inches of soil at approximately one part of ESCS to 3 or 4 parts of top soil. This treatment will promote a faster and more uniform growth, with stronger, healthier roots. This procedure also applies for flower beds or wherever soil has a tendency to pack or drain too easily.

For established greens, tees or lawns, the treated area should be spiked with standard spiking equipment. ESCS should then be spread over the spiked surface and dragged with back of rake or similar technique into the spiked cavities. Excess material may be spread over apron area. Treated area should be watered thoroughly after ESCS application to properly work it into the soil.

ESCS cannot burn or damage growth. The quantity or rate of application can never be excessive. ESCS can be blended easily with fertilizers and other soil nutrients and because of its moisture retention ESCS provides an excellent chemical or liquid fertilizer extender.

**University Experiments:** ESCS was used as a soil conditioner in nine existing greens at the Municipal Golf Course. After the greens had been aerated, a blend of 1/3 soil conditioners, 1/3 peat and 1/3 local soil was worked into the 1/2" diameter holes quite easily under the supervision of the University. Grass spread across the holes quite rapidly. Within a week it was difficult to see aeration marks. This treatment was reported five months later with similar results. The above treatment has softened the greens and has almost eliminated "brown spot" fungus. The grounds keeper and Pro reported that ESCS soil conditioner works better than natural sand for various reasons. After a few waterings, natural sand migrates to the bottom of the holes, soil conditioner does not. The minus #50 fraction of natural sand stratifies, thereby reducing water penetration. Moisture retention of soil conditioner is good for the grass roots.

In another ESCS experiment seven 1000 foot square plots were sown with seven varieties of blue grass using 1/3 the normal rate of grass seed. After seeding, 5/16 + #8 soil conditioner was spread on the surface of 1/2 of each plot 1/2 inch deep to be used as mulch. Observations when the plots were 14 weeks old indicated that in every case the soil conditioner half had at least 50% more growth and was quite weed free. Later observations indicated the soil conditioner half was still 40% ahead of the competitive half. In addition, the soil conditioner half germinated in

five days instead of the usual ten or more days and a good stand of grass was grown with only 1/3 the normal seed application.

**ESCS Offers Big Advantages:** Some of these advantages are listed below.

The use of less water and water better: ESCS absorbs water faster, yet holds more water longer at the root level, where it is needed.

One application conditions soil indefinitely: ESCS will not dissolve, disintegrate or settle out. It maintains its position in the top 3 to 6 inches of soil-indefinitely.

A healthier turf is built with minimum maintenance: ESCS aerates the soil for deeper rooting, stronger growth. Better drainage promotes disease resistance. Non-toxic, odorless ESCS outlasts and outperforms any known competitive material...with less labor.

A better playing surface is provided in any weather: ESCS reduces turf damage by improving the playing surface. It absorbs surface water for better play in wet weather, holds moisture for a healthier turf in dry weather.

New Greens and others areas: For new turf, golf courses and new greens, ESCS should be worked into the top three inches of soil. This treatment will promote faster and more uniform growth with stronger, healthier roots. This same procedure applies for flower beds and shrubbery or wherever soil has a tendency to pack. Can be used on lawns anywhere!

Established Greens: Spike the green or lawn with standard spiking equipment. Then spread ESCS over surface and drag with back of rake or similar technique. Excess material may be spread over apron area of the green. When finished water green thoroughly.

**Lite-Wate [ESCS] for Golf Green Maintenance:** The following information is excerpted from a letter sent by Bill Martin of Chandler Materials to golf course superintendents regarding the use of Lite-Wate (ESCS) for green maintenance, November 8, 1988:

The attached information is to inform you of a competitive product to pea gravel, the aggregate which is most commonly used as a porous draining media under greens. Our LITE-WATE [ESCS] aggregate is competitively priced with pea gravel. Our LITE-WATE is manufactured in Tulsa and is readily available for shipping to your location.

Presently, a new 18-hole course is being built at Choctaw called Choctaw Creek. The LITE-WATE aggregate is now in-place and covered with a sand-peat moss mix.



The Choctaw Creek green design is:

- A. A 4" perforated plastic pipe is buried in a trench and covered with Lite-Wate aggregate. The drain system is of the herring-bone design, to provide uniform drainage to all parts of the green.
- B. 4" to 8" of Lite-Wate aggregate depth is over the drain to act as a collection media for the storm water and sprinklers. The Lite-Wate substitutes for pea gravel. It is superior to pea gravel for two reasons:

The General Contractor at Choctaw Creek, says the Lite-Wate is much easier to spread than pea gravel, since it is roughly ½ the pea gravel weight.

Lite-Wate is very porous, and will hold about 25% of its own weight in water. It tends to keep the grass root system fed with water, and tends to regulate the internal green temperature, minimizing wide temperature swings. It will not break down due to fertilizer usage, and is chemically inert.

- C. A 12" thick blend of 90% Sand/10% Peat Moss was then placed over the Lite-Wate at Choctaw Creek.

Please consider a superior draining media, Lite-Wate aggregate, in your green rebuilding program, for the healthy greens your members and guests expect.

**The Use of Haydite [ESCS] in Construction and Maintenance of Golf Course Greens at Colonial and Shady Oaks Country Clubs in Fort Worth, by Cedric Willson, TXI, September 29, 1965:** This is a brief report on the experience of two Fort Worth country clubs in using Haydite [ESCS] fines (#4 to 0) graded as shown in Table 15.2 for the construction of golf greens and green maintenance. There was no scientific approach to these applications. The work was done in accordance with practical knowledge and the judgment of head greens keepers and chairmen of the golf greens committees. I will report the results obtained by the use of Haydite as compared to green construction in which natural sand or calcined clay was mixed with the sub-soil. No one involved in this work can explain, from the standpoint of soil science, why these results were obtained. I will include some opinions as to the reasons for the results but it should be understood they are entirely laymen's ideas and have no scientific background.

Colonial in Fort Worth is one of the finest, if not the best golf course in the Southwest. Members take great pride in the condition of the entire course, particularly the greens, and spare no expense in maintaining them in the best

possible condition. The annual Colonial Tournament is one of the top five or six in the nation.

Shady Oaks was built by a Fort Worth multi-millionaire primarily for his own pleasure. A few of his friends were invited to become members. He spared no expense in building the course and money has been no object in its maintenance during the five years since it was constructed. Both clubs have tried every soil conditioning material known to them in their green construction and maintenance programs, some costing up to \$50 and \$60 per ton.

In September, 1963 the Colonial Head Greenskeeper and the chairman of the Greens Committee talked to us [TXI] concerning their green maintenance problem. The bent-grass root structure was from 6 to 10" deep in the spring and early summer but during July, August and September, the depth of the roots became less and less to where it was no more than 2" deep by October of a normal year. Watering the greens, even to excess, did not hold the root structure down and the grass on the greens lost its resiliency, wore thin due to the heavy player load, and generally was unsatisfactory. The grass revived somewhat when cool weather and winter rains came but it was March or April of the following year before they were back in good shape. Since the course is played all year, this unsatisfactory cycle went on and on.

They thought better sub-soil drainage might help this situation and requested a recommendation as to the proper size and gradation of crushed limestone which they believed might improve drainage if placed in a bed below the soil. It was our opinion this would not solve their problem and there would be nothing gained by installing the crushed limestone sub-base. Our suggestion was to replace natural sand or other granular material which had been mixed in the soil with Haydite fines. We thought the absorption of Haydite would hold moisture in the soil which would do some good in maintaining the deep root structure they wanted during hot, dry summer months.

They decided to try this on No. 11 Green and, early in October, replaced about 16" of sand/soil with a similar depth of a soil/Haydite mixture. Half of the green was 50/50 Haydite and soil while the other half was 1/3 Haydite mixed with 2/3 soil by volume. The bent-grass which had been peeled off was replaced even though it was in poor condition since it had just been through the bad three months previously referred to. This job required about 120 cubic yards of Haydite.

By the following April, this was by far the best green on the course but no conclusion was drawn waiting the critical July, August and September months. To everyone's surprise, including mine, an inspection in October showed the green to be in about the same condition that it was the previous spring and one did not have to be an expert to see a marked difference between this green and each of

the other seventeen. When I inspected it last month after two years, it was in the same superior condition with respect to the other greens as in the fall of 1964.

During this inspection, the greens keeper bored holes in several places using the tool he uses to set the cup. These holes were approximately 14" deep. In putting my hand down in these holes to the bottom, I noticed that it was always cooler than it was on the surface of the greens. The earth plug which came out of the hole was carefully examined and it was found the fine bent grass root structure ranged from 4 to 6 or 7" in depth.

This inspection procedure was repeated on several nearby greens where the sub-soil had been mixed with sand graded in accordance with the United States Golf Association recommendations or with some of the materials sold for golf green soil beneficiation such as calcined clay, etc. In every case, the "scientific" procedure of sticking my hand down to the bottom of the hole indicated the temperature was warmer than it was on the surface. The ambient temperature was about 100 degrees on this particular day but, even under these conditions, the bottom hole temperatures seemed higher than on the surface, particularly on the sand/soil greens. In fact, a few of them were so warm it was uncomfortable to leave my hand in the hole more than a few seconds. The root structure in the plugs which were removed was also examined and found to average not more than 2" deep on all of the greens explored other than No. 11. The effect of this much shallower root structure was evident in the poor condition of the grass as compared to No. 11. All greens had received about the same amount of watering.

The Head Greens keeper at Colonial and the Chairman of the Greens Committee are convinced it is the difference in temperature due to the insulating properties of the Haydite rather than its absorption which has been responsible for the results obtained on the No. 11 green. The cooler sub-surface temperature is the important factor which they believe has held the root structure down. At this time we have absolutely no expert opinion or scientific data to support this thinking.

Needless to say, the people at Colonial are delighted with the results obtained from their use of Haydite and enthusiastically say it is the finest material available for blending with the soil. The No. 11 green was inspected very closely in respect to the two different blends used. While there was not much difference, it was finally agreed the grass was in slightly better condition in the area where the blend was 1/3 Haydite and 2/3 soil as compared to the 50/50 area.

The immediate reaction of the greens "experts" at Colonial, which include Ben Hogan and Byron Nelson, was to rebuild the sub-soil on the other 17 greens following the same pattern as used for No. 11. The schedule for this reconstruction showed that the time involved and the number of days during which one or more greens would be out of service made this impractical. It was then decided to make an attempt to accomplish somewhat the same thing by a



systematic program of “plugging” the other greens, working on a small area at a time so they would remain playable.

This procedure consists of blocking off an area from 100 to 150 sq. ft. and removing plugs which are approximately 1 1/2" diameter by about 4" deep on approximately 3" centers. They used a steel mat made out of grating in order to have a pattern for the plugs. A small amount of Haydite is swept through the mat into the bottom of each of these holes and the plugs are replaced and the surface of the green is rolled. After this operation is completed, it is difficult to tell where the plugging was done.

The greens keeper cut a number of large plugs using the tool for setting cups in areas on some of the greens where this treatment had been completed for a year or so. An examination clearly showed there had been some lateral migration of the Haydite so that, to some degree, there was a continuous blend of soil and Haydite laterally across the area down to a depth of 4 or 5". The greens keeper pointed out that areas which had been “plugged” or “topped” were in better condition than areas on the same green where this had not yet been done. As an amateur inspector, I agreed, although, just possibly, somewhat prejudiced.

The success of the work at Colonial was carried to Shady Oaks by the greens keeper and Ben Hogan who plays both courses. They immediately commenced a similar program of “topping” which has now been going on for about a year. I have not had time to walk over this course but the man who built it told me they were pleased with the results and plan to continue until they have treated all eighteen greens.

In order to properly evaluate this story, certain facts should be made clear. In North Central Texas, as well as other areas in the Southwest, there is very little rainfall in a normal year from early in June until late in September. The maximum temperature day after day during this period ranges from the mid-90's to well over 100 degrees. Some years, there are as many as 30 days or more of maximum temperatures of 100° or more and the average is probably between 15 and 20 days. While the relative humidity may be 70% or more in the morning, it is generally in the 20's or low 30's during the afternoon and evening. The wind is usually out of the Southwest at velocities from 10 to 25 mph or more. These weather conditions generate forces of evaporation which are probably much greater than found in many other sections of the country and this undoubtedly creates a more severe problem in maintaining good grass on golf course greens. In other words, the greens at Colonial might have been in much better condition if they had gone through the typical summer weather of some other area and the obvious and somewhat amazing difference in the mediocre condition of the other 17 as compared to the excellent condition of No. 11 might not have been nearly as great.

Properties of the Haydite used should also be mentioned. The aggregate produced at our [TXI] Dallas plant is lighter in weight and has a higher absorption than most expanded shale's. The #4 to 0 fines which were used run about down the middle of ASTM C 330 gradation for this size and the loose dry weight is approximately 44 pcf. Absorption is 25% by weight. It is entirely possible that a heavier aggregate with a lower absorption would not have delivered the results which were obtained at Colonial.

In exploring other materials which are used to mix with and beneficiate the sub-soil for golf course green construction, we have found a number of comparatively high-priced materials on the market which are widely specified by golf course architects and used throughout the country regardless of local weather conditions. They are generally some type of calcined clay which has a high absorption but is not strong and durable when compared to our type of aggregate. After a few years, they disintegrate and become part of the soil so their beneficial effect, if any, is temporary as compared to the indefinite life which could be expected from expanded shale, clay or slate. These special materials are bagged and sell for prices ranging from \$20 to over \$50 per ton. It would appear this may be a very attractive market for our type of aggregate provided it could be shown by scientific investigation that the results obtained at Colonial could be expected with our material in other areas of the United States and Canada.

In past years, many greens have been constructed by mixing natural sand with the sub-soil. The Corp and Soil Sciences Department at Texas A & M has developed a specification for the United States Golf Association which is the one most generally recognized. It includes natural sand but the recent trend seems to be towards some type of specially manufactured product such as the calcined clay. Some of these materials have been investigated at Texas A & M.

It is my opinion that such an investigation of our material would show a special gradation was required. This might be a well-graded aggregate from #4 to #30. I feel sure our material would have done an even better job at Colonial if 100% had been retained on the #30 sieve or possibly the #50. I have had no contact with Texas A & M for about a year but presume their proposal which was mentioned at the Miami meeting in 1964 is still good. I suggest any work contemplated be done at this institution. They have done the work in developing specifications and recommendations for golf green construction which has been sponsored by the United States Golf Association and this prestige would lend authority to any report they make.

Cedric Willson

**Table 15.4 Texas Industries Laboratory Aggregate Sieve Analysis**

Identification: Dallas Haydite From: Silo

Date Received: 9/30/65

Grading Designation: #4-0 Fines

Unit Weight, lb/cu. ft.: 44.7 D. & L.

Sieve Size	Cumulative Percent Retained	Percent Passing	Required Percent Passing
¾ in.			
½ in.			
3/8 in.			100
No. 4	0	100	85-100
No. 8	3.5	96.5	
No. 16	38.0	62.0	40-80
No. 30	66.7	33.3	
No. 50	84.9	15.1	10-35
No. 100	89.2	10.8	5-25
Pan			
	F.M. 2.82		

## 15.5 Surface Applications

### **Architectural Ground Cover (decorative and insulating)**

ESCS stonescaping is a permanent solution to decorative landscaping. The inherent, natural beauty of ESCS aggregates are aesthetically pleasing and provide a superb background for landscaping shrubbery.

ESCS aggregates are completely stable, inorganic and will not decompose or change color even in the most severe environment. Areas landscaped with ESCS require minimal maintenance. When placed over plastic sheeting grass and weeds are minimal and the architectural effect on the area will remain. Whether for walkways, garden enhancements or ground cover it hides unsightly or hard to maintain soil.

Unlike some ground covers landscaping ESCS will not rot nor deteriorate, is unaffected by winter freezing and thawing cycles, is fireproof and chemically inert. It will not harm flowers or shrubs, nor react with sprays or fertilizers. Its cellular structure gathers and retains available moisture for added plant protection and nourishment. The cellular structure also makes landscaping ESCS much easier to handle by reducing the weight to nearly half of that of most natural stone aggregates.

Suggested coverage is 2" deep, or for absolute weed and grass control, 4" of landscaping ESCS or 2" of the product applied over a plastic film is recommended.

Uniform grading of plus 1 1/2 " x 3/4" and a dependable and ample supply makes matching future applications to established beds an easy matter.



**Figure 15.16**



**Figure 15.17**



**Figure 15.18**



**Figure 15.19** *Decorative Stone Scaping*

### **Sub-Surface Insulating Loose LWA Fill**

Thermal conductivity of Loose Lightweight Aggregate Fill: The following information on thermal conductivity is provided to assist engineers when designing thermal sensitive projects, i.e. frost protection for underground water lines, insulation around or under thermal sensitive vessels, etc.

Moisture has a significant effect on thermal conductivity of granular insulating fills. The thermal conductivity increases about 4% per one-percent moisture for expanded shale, clay and slate lightweight aggregate and increases 7-9% per one-percent moisture for natural sand and gravel.

The practical in-place “k” values for insulating fills depends on the equilibrium moisture content of the fill, which varies depending on the environmental

conditions. Where protected conditions exist like core insulation inside concrete masonry units or fills protected by water proof membranes, a “k: value multiplying factor of 1.1 to 1.2 is commonly used. Where unprotected conditions exist like in large geotechnical fills or insulation around underground utility line, a multiplying factor 1.8 to 1.9 is commonly used.

**Table 5. Weight and Thermal Conductivity values  
for Expanded Shale, Clay & Slate Lightweight Aggregate**

Dry Weight lb/ft <sup>3</sup>	Thermal Conductivity, k <sup>1</sup> , Btu/hr ft <sup>2</sup> (deg F/in.) (W/m deg C)	
-------------------------------------	---	--

Coarse 3/4 " or 1/2 " to #4<sup>2</sup>

20	.68	(0.097)
30	.83	(0.119)
40	.93	(0.141)
50	1.13	(0.163)
60	1.29	(0.185)
70	1.44	(0.207)

Natural Granular Fill (Sand with clay and gravel)

110	7.5 – 8.5	(1.2 – 1.3)
120	9 – 12	(1.35 – 1.7)
130	11 – 15	(1.6 – 2.2)
140	13.5 – 20	(1.9 – 3.0)
160	21 – 35	(2.6 – 5.0)

1. K values were taken from “*The Thermo-physical Properties of Masonry and its Constituents, Part I, Thermal Conductivity of Masonry Materials*”, by Rudolph C. Valore, Jr.
2. The K values for Fine or Coarse/fine blend averages 6% lower.

**Pipe Backfill:** The following is excerpted from a report “*Insulating Backfill for Shallow Buried Watermains*” Dilger W.H., January 1991.

The depth of soil cover over buried water pipelines in the City of Calgary as well as any northern urban area is dictated by the depth of frost penetration in the local soils during the winter months.

Until recently, the design criteria used by the City of Calgary Waterworks Department required a minimum depth of cover to the pipeline of 2.7 meters (9 Feet) in clay soils and 3.3 meters (11 Feet) in gravel soils. Installation of pipers



and repair of broken pipes in such deep trenches is expensive, particularly in winter month when soil is frozen.

In 1988, a research program was launched with the objective of investigating the effectiveness of Granulite, a lightweight, insulating aggregate used as an insulating backfill in water main trenches, thus allowing the installation of water pipelines in much shallower trenches.

Granulite is a lightweight, granular material manufactured in rotary kilns from natural clay or shale. In appropriate circumstances the insulating value of the Granulite is many times greater than that of natural soils. Granulite, being a ceramic material has relatively high strength, is chemically stable and environmentally safe. Similar materials have been used for this purpose in many European countries.

The original test program was conducted over the winter of 1988-1989 and consisted of the construction and instrumentation of twelve test trenches. Frost penetration measurements were made and thermal properties of the Granulite and backfill materials were established. The results are documented in a report entitled "*Frost Penetrations of Underground Water Pipes*", Dilger July 1989.

Conclusions: It has been most useful to have a "second look" at the significant thermal characteristics of Granulite after one year of burial under actual operating conditions. The results of this testing program have shown that Granulite maintains fairly constant moisture content and thermal conductivity values in trench conditions, over a long term.

The stability of these thermal parameters has indicated that no change in the design factors used to produce the original trench cross-section is warranted. Thus, the original trench design has been confirmed as valid for Calgary winter conditions.

These conclusions provide support for the general concept of narrower, shallower trenches for the burial of watermains insulated against frost by Granulite backfill. In the case of the City of Calgary, reduced burial depth in the order of 0.6 to 1.2 meters has been made possible by insulating the watermains. This construction feature makes maintenance of the system faster, more convenient and less expensive, particularly in winter months.

Granulite offers the designer of underground utility systems the opportunity to modify frost penetration patterns, thus providing trouble free performance of the utility, often at reduced initial construction costs.



**Figure 15.20 Calgary Pipeline, Calgary, Canada**  
*Engineers: City of Calgary/Pildysh and Associates consultants, Ltd.*

Watermains must be installed below the level of frost penetration. In Calgary this requires deep, wide trenches. Such trenches are expensive and often dangerous to workers. The insulating properties of LWA fill allowed engineers to reduce trench depth from 3.3 meters to 2.1 meters. This provided safer working conditions and reliable freeze protection with an environmentally “friendly” material. LWA backfill will also afford easier winter excavation for pipe repair, reduce disruption of water supply and street traffic by decreasing construction time, and eliminate the need for synthetic insulating board and wide trenches. With LWA backfill, present and future savings in capital costs alone are expected to be in the millions.

### **High Temperature Protection**

In 1983, McClelland Engineers, Inc., was retained to design a shallow foundation for supporting a hot asphalt tank operating at a temperature of 500 °F. The search for a suitable foundation insulating material led to the possibility of using a lightweight aggregate. Since data on the engineering properties of the locally available lightweight aggregate was very limited, laboratory testing was performed to measure the strength, density and conductivity characteristics of the material. In addition to this application, it was recognized that the material’s light weight coupled with its high angle of internal friction makes it useful for other applications such as backfill behind bulkheads or for raising site grade in areas of soft soils. Engineering properties as well as new applications for the lightweight aggregate are discussed in this paper.

Thermal conductivity tests: The thermal conductivity of the lightweight aggregate was measured in accordance with the ASTM C 518-76 procedure entitled “Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter”. The tests were performed on two specimens of medium aggregate. Each specimen was approximately 20 inches square and 8 inch thick. The tests were performed using a Dynatech Model R-Matic heat flow meter. The tests were performed on samples in a loose as well as in dense condition. The apparent thermal conductivity of each sample was 0.086 Btu/hr ft F°.

**Table 15.5 Comparison of Properties – Lightweight Aggregate and Soil.** The following table gives a comparison of properties of lightweight aggregate and typical soils.

Property	Lightweight Aggregate	Natural Soils
Maximum dry density, pcf	54-59	105-115 (sand)
Maximum wet weight, pcf	67-71	110-120 (sand) 115-135 (clay & gravel)
Angle of internal friction, degrees	35-40	30-38 (sand) 35-40 (gravel)
Thermal conductivity, Btu/hr ft °F	0.09	0.25-1.0

In summary, the lightweight aggregate has typically a unit weight equal to half of the unit weight of soils. The angle of internal friction of lightweight aggregate is comparable to a dense sand or gravel.

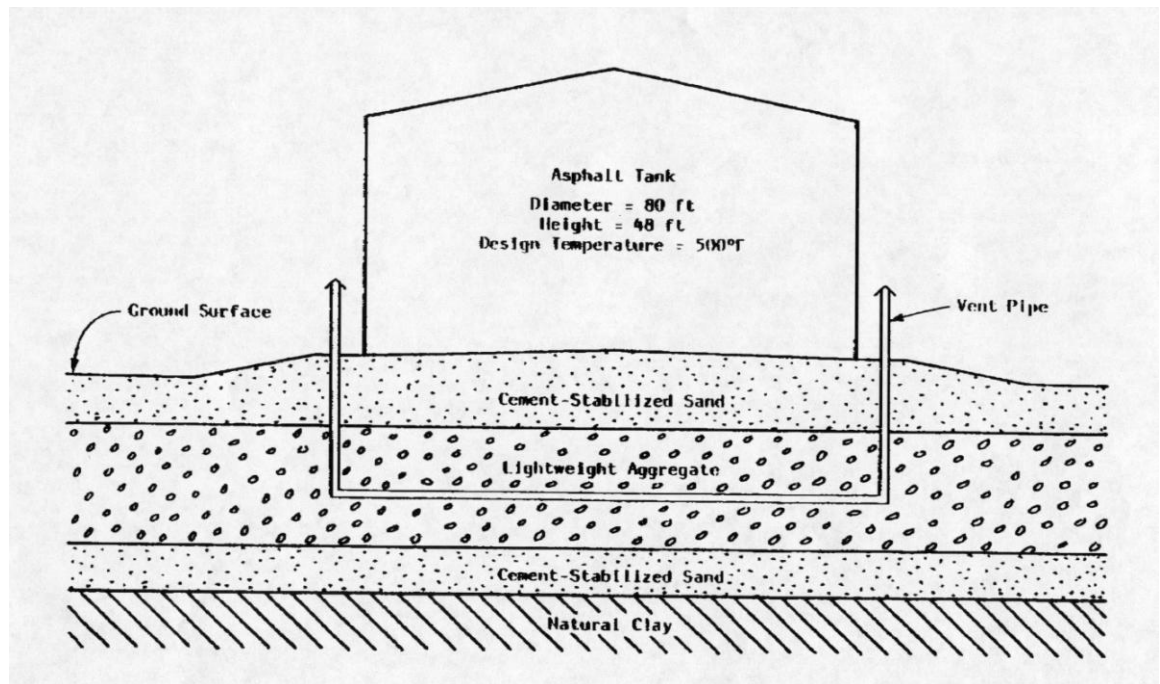
Application of lightweight aggregate: The lightweight aggregate has traditionally been used for making lightweight concrete. By replacing the normal aggregate (e.g. sand and gravel) by lightweight aggregate, the density of the concrete can be reduced to 100 pcf from the normal 150 pcf. However, due to its light weight, high friction angle and low conductivity, the lightweight aggregate can also be used as an insulating material under hot and cold structures, as a lightweight angular backfill behind retaining structures or as a lightweight fill to raise grad. Three typical geotechnical applications of lightweight aggregate are described below

Hot asphalt tank: A lightweight aggregate was recently used as an insulating material under a hot asphalt tank with a design temperature of 500 °F. The tank is 80 ft in diameter and 48 ft. high. The insulating material under a large hot tank must have (a) low thermal conductivity, (b) high shear strength, and (c) low compressibility. It should also be economical, easy to compact and stable under heat and it should be durable. In the past, limestone, sand, shell, lightweight concrete and occasionally blast furnace slag have been used.

The lightweight aggregate met all the requirements for use and was more economical than lightweight concrete. The lightweight aggregate had a lower

thermal conductivity and was considerably lighter than the blast furnace slag. For the hot asphalt tank, the authors designed foundation system consisting of an upper cement-stabilized sand layer, a 5-ft-thick layer of lightweight aggregate and a bottom cement-stabilized sand layer (Fig. 15.21). This foundation system is expected to reduce the soil temperature from 500 °F at the tank bottom to 200 °F at the bottom of the foundation.

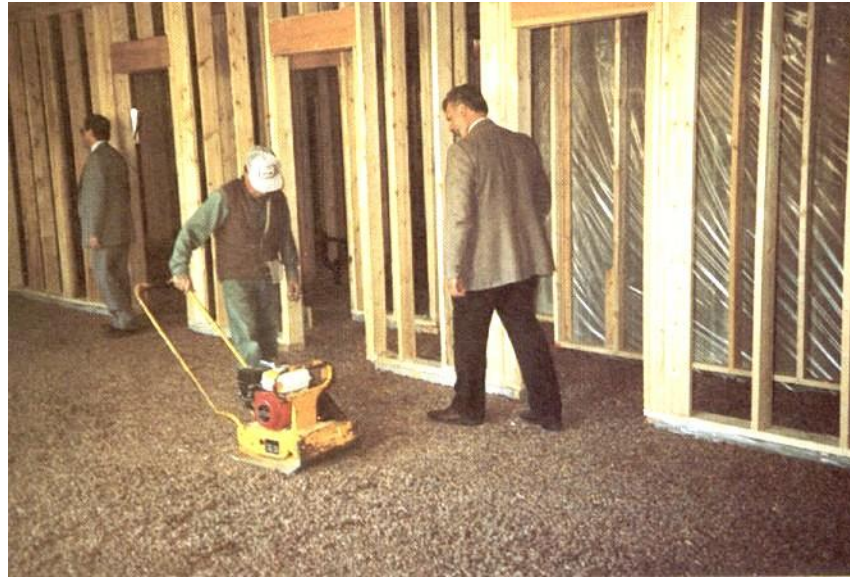
The tank was constructed in mid 1984 and hydro tested in late 1984 and has performed satisfactorily during hydrotest. Thermocouples were installed under the tank to measure in situ soil temperature. The tank is expected to be in operation shortly.



**Figure 15.21 Asphalt Tank**

To our knowledge, this is the first time a lightweight aggregate has been used for this application. The use of a shallow foundation system has resulted in a considerable savings to the client from the original pile-supported foundation. The authors have since then designed shallow foundations using lightweight aggregate for two hot oil tanks having diameters of 150 ft. and heights fo 48 ft. The design temperature of the hot oil tanks is 350 °F..

**Under slab on grade** – ESCS has a history of use as insulating granular sub-base under basement slabs in residential and commercial projects. In addition to providing insulation, the open-graded LWA serves as capillary break, a reliable drainage medium



**Figure 15.22** *ESCS as insulating granular sub-base under Basement slabs in residential and commercial projects.*

**Perimeter insulation** – ESCS as a perimeter insulation under slabs on grade has a long history in Europe. In this application, the ESCS is used as a sub-strate under the slab with a increase in thickness at the perimeter where exposure to cold air is greater. The dimensions, thickness and details are directly influenced by the thermal conductivity of the loose LWA fill. Because of the greater concern for energy conservation the thermal conductivity of European loose LWA tends to be lower than North American LWA due to the generally lower bulk density.

### **Insulation of Radiant Heated Floors**

ESCS sub-strate for ground floor heating coils prevents heat losses and increases efficiency of the heating system. The insulating value of ESCS is 25% of Styrofoam (that is 1" Styrofoam = 4" ESCS) as established by research conducted by the Canada National Research Council and the University of Calgary.

No gravel bedding is required under ESCS layer. Heating coils and concrete floor slab can be placed directly on ESCS.

**Coverstone for Built-Up Roofs (To be developed, TBD)**

**De-Slicking/Traction for Icy Roads (TBD)**

**Fire Protection for Impermeable Plastic Liner (TBD)**

## **15.6 Specialized Non-Structural Concretes**

### **Lightweight, Non-Structural “Fill” Concrete**

Quite frequently ready-mix concrete and their lightweight aggregate suppliers are called upon by design professionals and contractors to supply lightweight, non-structural fill concrete. There are numerous possibilities for this very efficient concrete that from a density standpoint, falls somewhere between a structural concrete and an insulating concrete. Compressive strengths of 2500 psi for floor fill and 500 psi for roof fill are typical. For strength development of these non-structural concretes see Fig. 15.25. Typical mixture proportions are shown in Table 15.6.

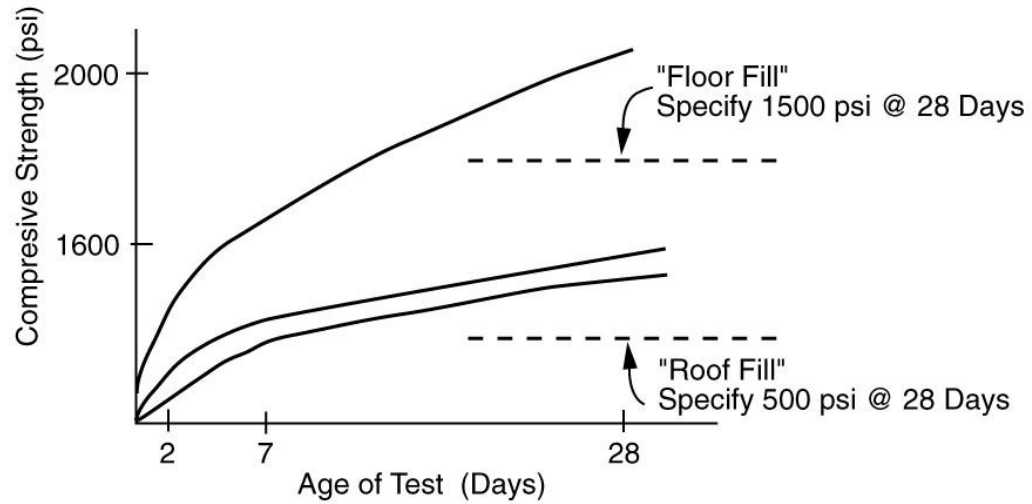
**Table 15.6 Mixture Proportions for Typical “Floor Fill” and “Roof Fill” Non-Structural Lightweight Concretes**

<b>Mixture No.</b>	<b>1</b>	<b>2</b>	<b>3</b>
<b>Cement (lb)</b>	<b>520</b>	<b>450</b>	<b>410</b>
<b>Water (lb)</b>	<b>360</b>	<b>340</b>	<b>340</b>
<b>Fine LWA (3/8-0) (lb)</b>	<b>1770</b>	<b>1730</b>	<b>1680</b>
<b>Total Weight (lb)</b>	<b>2650</b>	<b>2530</b>	<b>2430</b>
<b>Air (Air Flow 20) %</b>	<b>13</b>	<b>19</b>	<b>19</b>
<b>Slump (in)</b>	<b>5.0</b>	<b>6.0</b>	<b>6.0</b>
<b>Compressive Strength (psi)</b>			
<b>@ 2 days</b>	<b>635</b>	<b>355</b>	<b>320</b>
<b>@ 7 days</b>	<b>1100</b>	<b>605</b>	<b>525</b>
<b>@ 28 days (3 x 6)</b>	<b>2170</b>	<b>1030</b>	<b>930</b>
<b>@ 28 days (6 x 12)</b>	<b>2090</b>	<b>940</b>	<b>870</b>
<b>Density (lb/ft<sup>3</sup>)</b>			
<b>Fresh</b>	<b>98</b>	<b>90</b>	<b>90</b>
<b>@ 2 days</b>	<b>97</b>	<b>89</b>	<b>87</b>
<b>@ 7 days</b>	<b>96</b>	<b>87</b>	<b>87</b>
<b>@ 28 days</b>	<b>94</b>	<b>85</b>	<b>85</b>
<b>Oven Dry (Calculated)</b>	<b>82</b>	<b>78</b>	<b>74</b>
<b>Equilibrium (Calculated)</b>	<b>85</b>	<b>81</b>	<b>77</b>

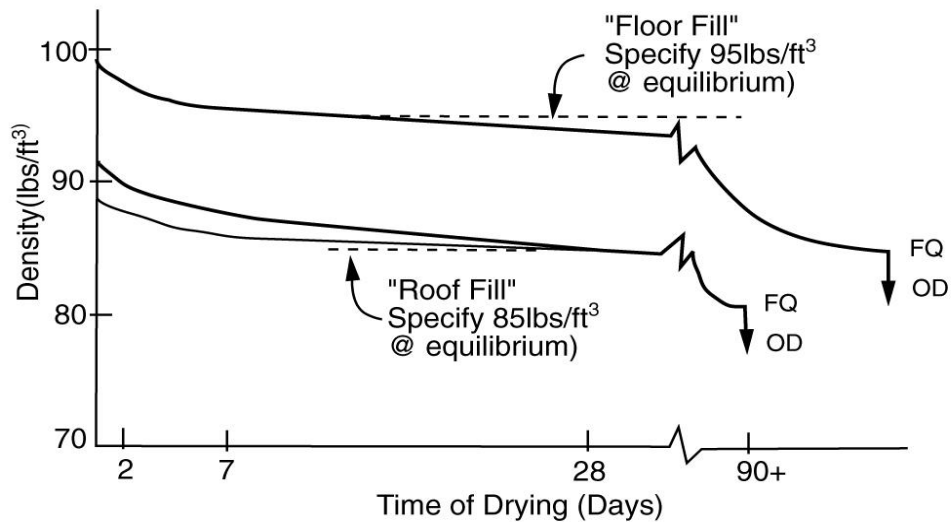


The results of this particular investigation could undoubtedly be improved using pozzolans, higher volumes of air entraining admixtures and lower density lightweight aggregates. The intention of providing these results is only to set up a template for further investigations.

One such application is the fill concrete on roof structures where the slope to drain requires concrete thicknesses of from as much as 12 inches feathered out to less than 1/2 at the drain. This highly functional concrete is best served by structural lightweight aggregate grading from 3/8 to 0 with a high air content. The effect of the high air content is two-fold. Obviously, there is a considerable weight reduction when air contents are in the range of 15 to 25%. Secondly, and less obvious, there is a significant reduction in the mixing water required to place this type of concrete despite it containing a high surface area fine aggregate. This is due to the untold millions of air bubbles that provide a ball bearing mechanism to create plasticity to the mix in lieu of the water of convenience generally necessary to provide adequate workability of the concrete for placing. The reduction in the water content in this mixture is significant in that these concretes do not usually require venting. This formation reaches an equilibrium moisture condition with ambient air in a relatively short period of time. As an example of this rapid decline in moisture content versus time consider Fig. 15.26 which shows three different high air, all fine lightweight aggregate mixes which were proportioned with air contents of from approximately 9 to just under 20%. Note that the most rapid decline in moisture content is in the first 7 to 10 days which is always a time element required before any roofing membrane could be placed on the concrete. Placing a roofing membrane that seals in moisture from the top and having little access for the moisture content to escape downwards is one source of roofing problem. The moisture may rise under the membrane at a later date, particularly in the first hot summer day with vapor pressure causing the development of bubbles under the roofing membrane. As shown in Fig. 15.26, a plot of the density versus time, these concretes tend to lose significant amounts of the free, uncombined water and reach equilibrium rather quickly. Unlike insulating concrete that use highly absorbent very low density aggregates (perlite, vermiculite) the water requirements of lightweight fill concrete using structural grade aggregates are low.



**Figure 15.25** *Compressive strength of fill concrete as a function of time.*



**Figure 15.26** *Density of concrete as a function of drying time.*

Water used in the production of fill concrete can be simplistically grouped into three areas; the first being that water required for the hydration of cement which is routinely taken as a fraction of the weight of cement, somewhere in the order of approximately 20 by weight. The second fraction of water required for workability is uncombined chemically, lost to the atmosphere and forms the

capillaries through which additional water can migrate. This water loss of the concrete is a function of the ambient environment, the thickness of the concrete and the degree of curing. This type of concrete reaches an equilibrium density in approximately 60 to 90 days.

The third is water that is held physically (not chemically). This water will not leave the concrete except under accelerated high temperature drying. This may be seen in the last part of the curve where concretes after reaching equilibrium were oven dried.

Strength requirements for fill concretes vary according to the application. When used as a slope to drain on roofs the only strength necessary is that required to provide a sound substrate for the roofing membrane and for usual construction loads on the roof. In general, a strengths of approximately 500 psi is required. As shown Fig. 4.13 the strengths of these fill concretes vary anywhere from 900 psi to over 2000 psi depending on the mixture formulations, cement and air contents.

Thermal resistance of these low density fill concretes is intermediate between the usual structural lightweight concretes and the very low density non-structural concretes and may be calculated by the equation which compares thermal conductivity versus density. This equation developed by Valore in ACI paper, February 1980, has been shown to be accurate for all ranges of lightweight concretes.

$$k_c = 0.5 e^{0.02 d} \text{ (inch pound unit)}$$

$$k_c = 0.072 e^{0.000125 d} \text{ (SI units)}$$

where  $d$  = oven - dry density in lb/ft<sup>3</sup> (kg/m<sup>3</sup>)

A major advantage of this semi-insulating, fill concrete is that it is extremely practical, as it can be batched by regular ready mixed concrete procedures (there is no bagging and filling of ready-mix trucks by hand). The concrete dries to an equilibrium density quickly, and has sufficient strength that often allows walking on the next day. Additionally, moderate structural and thermal insulating properties are also provided.

### **Pre-Mixed Bag Concretes**

After more than 2,000 years of reducing weight in structures, it should not be a surprise to learn that ESCS has been substituted for heavy aggregates in pre-mixed, bag mixtures that are widely used in consumer concrete applications.

The following information is directly lifted from a publication by Texas Industries, Inc. Lightweight Aggregate Division. "Now after years of development the benefits of lightweight concrete are available in Superlite™ concrete mix

An easy to use dry mix formulation, Superlite™ can be used with confidence for any project where conventional concrete mix is required. The secret to Superlite™ is the use of a special lightweight aggregate instead of the heavier pea gravel found in ordinary dry mix concrete. This aggregate is a unique kiln-fired ceramic crystalline structure, offering the strength of pea gravel while reducing weight by over 50%. Superlite™ also employs a higher proportion of cement-to-aggregate, ensuring its strength and long term durability”.

## **Shotcrete**

Portland cement shotcrete is an exterior wall covering which, if properly applied, fulfill all requirements of durability and gives a satisfactory appearance. Attention should be called to the fact that shotcrete is the term applied to all types of pressure applied Portland cement plasters furnished under various trade names such as: Gunit, Jetcrete, Bondact, Colorcrete, etc.

The basic ingredients are Portland cement, fine aggregate, and water, and special chemical and mineral admixtures.

ESCS Shotcrete: Expanded shale lightweight fine aggregate has been used for shotcrete since 1948 with good results. Most of the activity has been on the Pacific coast and in the Southwest, however, there have been interesting applications in other parts of the U.S. and in Canada, including the lining of a tall smokestack in a cement plant in Pennsylvania.

Apparently the major difference encountered in the application of ESCS shotcrete has been in the control of re-bound. Initially the operator experiences a somewhat greater re-bound, however by standing slightly farther away from the wall, the re-bound is controlled more easily. A number of operators have found that the rebound material can be reclaimed and reused without any detrimental effects.

Generally it is found that the ESCS fine aggregate should be damp for efficient operation...not necessarily soaked, but containing perhaps one half to two thirds of its total absorption.

In some cases adjustments in the nozzle velocity have been found helpful, but this is not always necessary.

As with natural sand, the gradation of the aggregate should be slightly on the coarse side, perhaps with a fineness modulus from 2.8 to 3.3.

Satisfactory results have been obtained with a mix proportion from 1:3 to 1:5 1/2.

### **Flair (Fine Lightweight Aggregate Internal Reservoirs-Admix Delivery System) (TBD)**

FLAIR-DCA consists of a unique method to control the distribution/delivery of chemical admixtures within a hardening concrete. Recently, the usage of saturated fine lightweight aggregates to provide internal curing water to promote cement hydration in hardening concrete with a low water to cementitious binder ratio ( $w/c \leq 0.42$ ) has been demonstrated in the laboratory and the field. The novel aspect of FLAIR-DCA is to utilize these same internal reservoirs to supply chemical admixture such as shrinkage-reducing admixtures, corrosion inhibitors, etc. to the concrete. As the cementitious components of the concrete react with the mix water, the hydration products occupy less volume than the starting materials. Thus, a concrete will imbibe water from its immediate surroundings or from internal sources to maintain a saturated capillary porosity. While to date, the internal reservoirs have been saturated only with water, they could equally be saturated with solutions of chemical admixtures.

Admixture deliver via these internal reservoirs can potentially offer several advantages over conventional delivery by direct addition to the mixing water. Some chemical admixtures such as shrinkage-reducing admixtures are partially absorbed by the cement hydration products. In this case, releasing the majority of the chemical admixture after some of the cement has already hydrated should result in a more efficient usage of the chemical. This would be the case should FLAIR be used to deliver the chemical admixture. Secondly, admixture combinations sometimes exhibit detrimental interactions. An example would be a shrinkage-reducing admixture that influences fresh concrete properties (air entrainment, rheology, setting) via conventional means and the admixture that influences hardened concrete properties (corrosion inhibition, shrinkage reduction, ASR mitigation) via the internal reservoirs, these detrimental interactions should be minimized.

### **Roof Fill (Insulation and Slope to Drain) Topping on Wood Floors**

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# **15A**

**ASTM D 5268**

**“Standard Specification for  
Topsoil Used for Landscaping Purposes”**

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# **15B**

**ASTM D 5883**

**“Standard Guide for Use of Rotary Kiln  
Produced Expanded Shale, Clay or Slate (ESCS)  
As a Mineral Amendment in Topsoil Used  
For Landscaping and Related Purposes”**

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# **15C**

**“Horticulture Applications for Lightweight  
Aggregates”**

# HORTICULTURAL APPLICATIONS FOR LIGHTWEIGHT AGGREGATE

By

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## INTRODUCTION

This paper will cover the horticultural uses of lightweight aggregate as related to use in the landscape industry only; specifically as a component in structural soil for urban trees and roof garden soil mixes. Discussion of applications for the greenhouse and nursery industry will be excluded because industry standards vary with each type of crop. Specifications, marketing techniques, and actual completed projects will be reviewed.

The business of horticulture is growing and will continue to grow. Currently, gardening is the number one outdoor activity in the United States that people participate in. The growth of the industry doesn't seem to be affected by economic down swings like what occurs with the construction industry. Mother Nature does not wait for the economy to improve, plants still need maintaining. My experience as a Landscape Architect and landscape contractor in North Carolina has reinforced my confidence that LWA is the solution to tough soil problems and will become a major player in the industry during the next decade. How quickly industry wide acceptance is achieved is a matter of marketing.

As Horticulture Product Director for the Carolina Stalite Company, I have found that the applications for LWA are not well understood by the Landscape Architects or contractors. The key to our success was being able to approach the designer as a fellow professional and get involved during the design process. The ability to present written specifications along with examples of successful projects has enhanced our credibility. To loose credibility just refer to soil as "dirt", I once had a soil professor who told the class that "dirt" is something that is tracked in onto the carpet. Always refer to it as soil or growing media. It takes a professional to provide consultation on product use. Being able to speak the language creates a definite advantage. Just providing product to a job site without expertise may backfire. A successful marketing strategy must include a knowledgeable sales staff. The following is a small portion of accumulated information and project tested specifications developed over a period of 12 years.



## I. Amending Heavy Compacted Soil

### Soil Compaction:

As difficult as soil can be to cultivate, few people ever think of it as the fragile growing medium that it is. Soils consist of three space-occupying components: solid particles, water and air. The volume composition for a soil in good condition for plant growth is approximately 25% water, 25% air and 50% solid particulate matter. But when good soils are compacted by any means the soil composition becomes less balanced due to the change in the soil structure. When the solid particles are pressed together, there is less pore space and the soil becomes hard and too dense for easy cultivation and proper root development. As a result the micro activity in the soil is reduced and plant performance is inhibited. Soils are not generic in structure, so why should the methods of conditioning them be?

### Soil Aggregation:

Different textures of soils (sand, silt and clays) have different compaction characteristics - some compact easier than others depending on varying particle size and presence of organic matter. Heavy soil compaction limits the movement of air, water and nutrients through the soil. This does not provide a favorable environment for the beneficial microbial activity necessary for healthy plants and turf. The *aggregation* of clay soil in the surface horizons can occur naturally if conditions are right. The slime from the decomposition of organic matter, along with the other viscous microbial products bind soil particles encouraging crumb development. This can be achieved by incorporating compost into the soil on a regular basis. Unfortunately with clay soil in the landscape, this process is almost always disturbed by compaction, poor drainage and anaerobic activity.

### Soil Amendments:

Foremost, the surface water must drain away. Water always runs down hill and standing water is a sign of trouble. The addition of underground drainage pipes may be necessary. The suggested practices of amending clay soils have changed a number of times during the past twenty years. Preparing holes for planting in clay soil keyed the phrase "creating a clay pot" situation. Just digging a hole and shoving a plant into it probably will not provide the results intended. However, digging a hole and filling around the root ball with loose organic matter may be just as bad. This is because the water in the soil will travel to the point of least resistance, such as the clay pot you just created. A plant will die just as quickly from drowning as from drought and the symptoms look curiously similar. The advantage of dry is you can always water, wet soil can not be instantly dried out. The use of peat moss alone in clay has not been recommended because of its wetting and drying properties. The addition of sand to clay if not properly proportioned can make a "brick". Eventually it was realized that the best alternative was to not add any amendments and install the plant material in constructed mounds of the native soil or artificial raised beds. Depending on the type of plant, this method did not always allow the plant to perform at its best. When possible, preparing the entire plant bed creates the best situation. The current use of pine bark fines and compost definitely benefit the plant, however the decomposition of pine bark creates slimes which tends to settle out and create an impervious surface at the transition zone of the soils. Compost will perform best if the soil is well aerated. The use of LWA can remedy this situation. Properly proportioned (about 35% to 50%) in the native clay with about 15% to 20% organic matter will continuously allow the exchange of air to

occur between the surface and soil. The other benefit of LWA is it allows the water to penetrate and move through the soil and because of the air space in the LWA particles, the roots can grow deeper into the soil which protects them from the summer heat and drought. It is important that the LWA particles be cubical in form rather than flat to provide the best drainage performance. The recommended method of bed preparation is:

### **Application Methods:**

- A. For heavy clays place 2" of LWA on the surface, work or till the LWA into the soil to a depth of 6 to 8 inches providing a 25% to 30% amendment for planting bed. Include ½ inches of compost to increase organic content if needed.
- B. For around existing planting, using a garden spading fork, loosen the soil around the drip line of the plant then fill the crevices with LWA to the surface, then topdress with compost.

## **II. Structural Soil**

Structural soil is an air-entrained mixture of quality aggregate and "soil" formulated to support various pavement types while allowing voids for air exchanges, water movement, organic matter, and root growth. Currently, most urban trees are planted directly into existing urban soil, tree pits with root barriers or expensive bridged pavement. The soil under pavement in areas adjacent to tree plantings is an important potential source of additional root space. Trees that are planted in areas surrounded by paving tend to struggle for air space and usually decline in ten years. The roots tend to take the path of least resistance searching for air, usually pipes or the surface. The need and desire for large trees in the urban landscape has been around for a long time. Unfortunately, the trees do not live long enough to fill the need. Not planning for root growth is ignoring the biological requirements of trees and is not economical. A product like expanded slate or shale (ESCS) as the main component of a structural soil can help give the roots additional air space while also providing the structural support for the pavement above. The additional space provided by structural soil will create tree growth and longevity that will meet the expectations of the designers. The failure to provide adequate soil drainage is the most frequent cause of newly transplanted trees dying. Insuring a good supply of air to the tree roots is essential for satisfactory tree growth. In urban situations, the movement of air into the soil is often restricted. Where there is heavy traffic supported by the soil in the root zone, structural soil is one solution where paving can be placed over the root zone.

Previously it was standard practice to backfill the plant pits around transplanted tree roots with a soil mixture that incorporated topsoil, organic matter, or directly into the existing material. Structural soil mixtures are used on urban sites where the backfill around trees has to support paving and pedestrian traffic. These mixtures use a porous aggregate such as Stalite expanded slate for 80 percent of the mix with the other portion consisting of a sandy clay loam with minimal organic content. This type of growing medium is designed to retain air when compacted to support paving.

Following the successes of Princeton, NJ Landscape Architect Henry Arnolds' work with air-entrained soils and the work of Jim Patterson, when he was with The National Park Service, the use of ESCS for structural soil makes horticultural sense. The porosity of the rock itself provides additional surface area for roots. I was called in 1995 to develop a specification for tree plantings in Atlanta for the up-coming Olympics. I contacted Dr. Patricia Lindsay who was with U.C. Davis at the time. Dr. Lindsay worked under Dr. Nina Bassuk at Cornell during the development of the CU-Soil. We were able to test and come up with a specification that satisfied the requirements. The compressive strength of the Stalite was high. Because the soil in the voids between the rock particles are not compacted, Proctor or CLB tests should be interpreted differently from natural soils. Because it is not a "soil", the objective in compacting structural grade aggregate fill is not to aim for maximum in-place density, but to strive for an optimum density that provides high stability without unduly increasing compacted density (crushing). We discovered the need for Hydrogels was eliminated by wetting the Stalite expanded slate. It retained enough water for the soil to adhere and remain attached to the aggregate even during transport and placement. The 1996 structural soil tree plantings for the Olympics in Atlanta are thriving after nine years. Since Atlanta, the National Park Service used this specification in 1998 for the retrofit to the Korean War Veterans Memorial in Washington D.C., 6-8" caliper lindens were planted and have been in place since without any fatalities. Twenty-three more Stalite Structural Soil projects have been completed since 1998 with the trees thriving while roots grow under the concrete. The trees in downtown Greenville, NC planted in Stalite Structural Soil survived hurricane Floyd in 1999. In 1998 Odell Associates in Charlotte implemented a structural soil plan to protect old oak tree roots under a new parking lot at the White Oak Plantation and recently it was done at the University of Virginia to protect an historic ash tree.

The cation-exchange-capacity (CEC) of soil is tremendously important to prevent nutrient loss from leaching. Since dense stone has a very low CEC, the need for additional clay in the CU-Soil is necessary for water and nutrient retention. If the structural soil is to be placed over structure (roof garden) CU Structural soil is NOT recommended due to weight, Hydrogel migration, and clay clogging filter fabric. Stalite has also developed a structural soil just for roof gardens. The CEC of Stalite is 26.9 me/100g which is very good and higher than some clays.

The advantages of ESCS over quarry rock are:

1. Cation-exchange-capacity of 20 to 25 me/100g
2. Roots can grow in 100% of the expanded aggregate without added soil
3. Water and nutrient retention
4. High water release curves
5. Less clay needed in the mix
6. No need for hydrogels
7. High compressive strength
8. Lightweight and easy to mix and work with
9. Contains voids for additional surface area for fine feeder roots
10. Additional air space available if soil proportion shifts

1. Holm, T. A., and A. J. Valsangkar. *Lightweight Aggregate Soil Mechanics: Properties and Applications, Transportation Research Record 1422*, National Research Council, Washington, D.C., 1993

Arnold, H. 1993, *Trees In Urban Design*. second edition Van Nostrand Reinold, New York

Lindsey, P. *The Design of Structural Soil*

## **II. Structural Soil for Turf**

The principle for structural soil for turf is basically the same as it is for trees, minus the paving. The structural soil acts as a support mechanism for the roots protecting them from pedestrian and occasional vehicular use such as in the construction of turf paths and fire lanes.

## **III. Lightweight Green Roof Media**

When physically evaluating the media it should be recognized that maintaining a green roof system is very different than what is performed at ground level. Media designed for placement above structures may have a weight requirement, and lightweight mixtures are recommended for planting where it is desirable to reduce the media weight. On green roof systems or other large planting areas over structures, the media can make a significant difference in the structural load. A media mixed with lightweight aggregate can reduce the saturated weight by 25 to 40% as compared to natural soils.

Until recently, providing a lightweight media suitable for green roof systems meant bringing in a typical nursery planting mix consisting of a blend of sand with peat moss or pine bark. Over a short period of time, organics will decompose creating two specific problems. First, the volume of mix decreases due to organic matter decomposition, requiring replacement. Second, as the organics break down, the fines filter out down to the separation fabric. Once settled on the filter fabric, the organic fines may decompose further creating an impermeable layer, which may impede the drainage causing the water to build up in the media. This may also increase the structural load and create plant health problems. Some structures have developed leaks because of this saturation problem. No more than 10% to 20% of the media should be organic. In arid climates replenishing organics after decomposition may be practiced to maintain the water retention properties of the media. Depending on local availability, composted organics is a preferred source for the organic component in green roof system media. However care must be taken when selecting the source of compost; proper stability/maturity, particle size, and feed stock source of the product should be considered. Certain composts may be derived from feed stocks that may include bio-solids from municipal sewage treatment facilities. These sources may contain very fine particulates, heavy metals and pathogens.

During the past several decades the performance of green roof system media has been evaluated in Europe and it was determined that the most crucial physical property the media should have is good drainage. This is made more challenging with the desire for green roof systems to retain additional water to not only reduce irrigation needs but also reduce runoff in urban areas. To address these performance issues, there are six properties that media should possess:

1. Good drainage and aeration
2. Water holding capacity (without getting waterlogged or heavy)
3. Nutrient holding capacity (cation exchange capacity - CEC)
4. Permanent, fully vitrified, not subject to breakdown requiring replacement (resists decomposition)
5. Lightweight but sturdy (to resist shrinkage and wind displacement)
6. Stable media with high internal shear capacity to support roots
7. Low thermal conductivity

ESCS as a primary component in, or used solo as a media, will meet the above requirements. ESCS, is a rotary kiln produced vesicular amorphous silicate particulate material. It is a highly porous, low-density material with a bulk specific gravity of approximately 1.05 to 1.80, and a dry/loose unit weight of approximately 35 to 65 pounds per cubic foot, (561 to 1041 kg per cubic meter). The pre-sized raw shale, clay or slate used to produce ESCS is fired in the kiln at a temperature between 1800° F (982° C) and 2200° F (1205° C). As it exits the kiln the material is sterile, inert, and ceramic. Some crushing may be performed to facilitate final screening in a screening system. ESCS is generally neutral in pH although the pH can vary somewhat depending on the raw material and the fuel used for processing. Test Method C 29/C 29M determines density (loose unit weight). Test Method C127 may determine the absorption after soaking the material. The particle distribution may be determined with the appropriate sieves as stated in Specification C136. The ESCS may be sampled in accordance with Practice D 75.<sup>2</sup>

In general, green roof systems can be categorized into two types, intensive or extensive depending on the plant material and planned usage for the roof area.

**Intensive green roof system:**

Intensive green roofs utilize a wide variety of plant species that may include trees and shrubs and are generally limited to flat roofs. Use of large plants requires deeper substrate layers, possibly 10 in (25 cm) or more, which results in more weight and a need for an increased structural load capacity of the building. Intensive green roofs usually have higher input requirements for water, labor and other resources than extensive green roofs.

**Extensive green roof system:**

Extensive green roofs use a narrow range of species limited to herbs, grasses, mosses, and drought tolerant succulents such as *Sedum* – a succulent plant known for its tolerance for extreme conditions. These types of plants can potentially be sustained in a substrate layer as shallow as 1.0 in. (2.5 cm) and, therefore, they can often be installed on buildings without the cost of major structural alterations. Extensive green roofs generally require less maintenance and are generally less expensive to install than intensive green roofs.

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<sup>2</sup> ASTM D 5883-96 (Re approved 2002) 5.2

ESCS is generally used in green roof systems as the mineral component of the media mix, as a granular drainage material, or as a media alone with no amendments. The hydraulic conductivity of the ESCS will differ depending on type and gradation. The gradation can vary from ¾ inch (1.9 cm) to fine sand like material. The media may require a blend of different sizes of ESCS with or without sand and/or an organic component depending on the application is for an *Intensive or Extensive* green roof. Variations in the media can be obtained by adjusting the gradation of ESCS to meet the desired porosity or weight requirement. The main adjustment that needs to be addressed is a correction for the weight and volume relationship of ESCS fines, that is, the minus No. 4 (4.75 mm) sieve size to a similar size of sand. The oven-dry or saturated surface dry/loose unit weight tests (see Test Method C 29/C 29M) can be performed to establish the weight-volume relationship.<sup>3</sup>

Care must be taken to specify what C 29/C 29M testing procedure (9.0) is to be used for ESCS fines (rodding 10.1, jiggling 11.1, or shoveling 12.1). Using the shoveling procedure to determine loose bulk density may result in the sample weighing less per volume moist than it will when dry because moisture tends to cause bulking of the ESCS fines that creates larger air pockets in the sample.

Typically, a loose cubic foot of ESCS fines will weigh approximately from 35 pounds per cubic foot (560 kg/m<sup>3</sup>) to 70 pounds per cubic foot (1120 kg/m<sup>3</sup>) depending on the source. Absorption of ESCS varies with the source, but is usually 9% to 35% of the oven-dry loose unit weight.

Because of the absorption differences between the types of ESCS, determining the amount of water release from the particles of ESCS may be important when specifying certain plant species. Care must be taken not to have the media hold too much moisture or pull needed water away from the roots. The absorption (ASTM C127) and the particle size distribution (ASTM C136) of ESCS can determine the porosity of the media. Providing good drainage and encouraging deep roots is essential when developing a green roof planting media.

<sup>2</sup> ASTM D 5883-96 (Re approved 2002) 5.2

<sup>3</sup> ASTM D 5883-96 (Re approved 2002) 6.1

See:

## **PRINCIPLES FOR SELECTING THE PROPER COMPONENTS FOR A GREEN ROOF GROWING MEDIA**

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<sup>3</sup> ASTM D 5883-96 (Re approved 2002) 6.1

# PRINCIPLES FOR SELECTING THE PROPER COMPONENTS FOR A GREEN ROOF GROWING MEDIA

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## **Abstract**

When selecting a growing media for a green roof system it should be recognized that maintenance of the system is very different than what is performed at ground level. Media designed for placement above structures may have a weight requirement, and lightweight mixtures are recommended for planting where it is desirable to reduce the media weight. Until recently in North America, many designers requiring a lightweight media suitable for green roof systems had specified a typical nursery potting mix consisting of a blend of peat moss or pine bark with some sand, vermiculite or perlite. Learning from mistakes of the past and following the lead of the German FLL green roof methods the industry has looked to provide a more mineral based media to sustain green roof plantings. Reducing the organic content and adding expanded lightweight aggregates can reduce the saturated weight of the media without losing volume due to decomposition. Because the topic of green roof growing media can encompass an entire day of seminars, this paper will concentrate on the types of materials available that can be utilized as green roof growing media or as a component of a blend.

My college soil science professor always reprimanded the class for referring to soil as "dirt". He would always say: "dirt is something that is tracked in onto the carpet". It also is commonly referred to as something politicians use to gain an edge on their opponents. In the green roof industry, "dirt" is something that the general contractor sneaks up onto the roof instead of the specified growing media. Most green roof professionals like the term growing media or medium, substrate, or planting media. Before getting involved in the green roof business, I experimented with what I called "engineered soils", but actually, for green roof media, there is often no soil added at all. There are a few definitions of what soil is, as a media for green roof systems I created my own definition: "the particulate matter or substrate that anchors the plant roots to sustain the plant growth". That is exactly what roof "soil" is supposed to do, but it does get complicated. For simplicity's sake let's call just call it the "media".

During the past several decades the performance of green roof system media has been evaluated in Europe and it was determined that the most crucial physical property the media should have is good drainage. This is made more challenging with the desire for green roof systems to retain additional water to not only reduce irrigation needs but also reduce and cleanse runoff in urban areas. To address these performance issues, there are six properties that media should possess:

1. Good drainage and aeration
2. Water holding capacity (without getting waterlogged or heavy)
3. Nutrient holding capacity (cation exchange capacity - CEC)
4. Permanent, fully vitrified (resists decomposition)
5. Lightweight but sturdy (to resist shrinkage and wind displacement)
6. Stable media with high internal shear capacity to support roots

Natural topsoil that is excavated from the ground should never be recommended for green roofs unless screened, sterilized and graded to meet the criteria for green roofs. Before designing the media we must determine the type of green roof system it will be applied to. The industry has adopted the terms for two types of green roof systems from the German FFL Green Roof Guidelines, *extensive* and *intensive*. There can be some variations, however the main distinction between the two is the maintenance required to sustain the system.

a. Intensive green roof system:

Intensive green roofs utilize a wide variety of plant species that may also include trees and shrubs. Use of large plants requires deeper growing media layers, possibly 6 inches (15 cm) or more, which results in more weight and a need for an increased structural load capacity of the building. Intensive green roofs are often accessible to the general public and can create a park-like atmosphere. Higher input requirements for water, labor and other resources are standard. (1)

b. Extensive green roof system:

In contrast, extensive green roofs use a narrower range of species limited to herbs, grasses, mosses, and drought tolerant succulents such as *Sedum* – a succulent plant known for its tolerance for extreme conditions. These types of plants can potentially be sustained without automatic irrigation in a media layer as shallow as 1.0 inch (2.5 cm) and, therefore, they can often be installed on buildings without the cost of major structural alterations. Extensive green roofs are generally not accessible to the public and have lower input requirements for resources. They require less maintenance and are generally less expensive to install. Mosses, succulents such as *Sedum*, and low-growing grasses are common selections for extensive systems. (1)

The media utilized for extensive systems and for intensive can be different and in some cases should be different. Extensive systems, usually but not always have a shallow media layer, normally 3 to 4 inches. The air content at maximum water capacity of 35% or more should be greater than 10%. The water permeability should be greater than 0.0001 cm/sec. (2) When possible, (except with weight restrictions) the deeper the better. Plants always perform better with deep roots. By allowing the surface to dry, green roof media encourages the roots to grow down away from the extremes of the surface environment. I have grown sedums on the ground in Carolina red clay and they have done fine, but on the other hand, picture a roof as a large frying pan, it is a harsh microclimate. When designing an intensive green roof you can grow many plants on top that also grow well on the ground but they must be able to thrive in the same microclimate. The air content for intensive systems at maximum water capacity of 45% or more should be greater than 15%. The water permeability should be greater than 0.0005 cm/sec. (3) Some shallow extensive systems, especially in Germany, have sedums planted in crushed roof tile or coarse lightweight aggregate with a thin topdressing of compost. Usually with no irrigation, these green plants thrive once established. However, in North America, our climatic changes are extreme, therefore supplemental irrigation may be needed. Coarse extensive media is almost always reserved for succulents. Intensive media has more of a soil like appearance but still must drain and have physical characteristics applicable to green roofs. Intensive media is a blend of two or more components with particle sizes graded to provide the bulk density necessary to grow a wide variety of plants. Media designed for intensive systems can also be used for extensive, the climate, plant material and depth usually determines the blend. See Figure. 1. The depth necessary to sustain plant growth depends on species and maintenance practices. A rule of thumb guideline is shown in Figure 2.



## CONTENT BY VOLUME

### INTENSIVE

- lightweight aggregate 35%-60%
- coarse sand (USGA) 25%-50%
- organic (compost) 5%-20%

### EXTENSIVE

- lightweight aggregate 60%-100%
- organic 0%-25%
- coarse sand 0%-35%

Figure 1: Component Content By Volume

## Green Roof Media Depths

Plants	Minimum Media Depth
Sedums	1" to 3" +
Groundcovers and Grasses	8" to 10"+
Shrubs	18" to 24"+
Large Shrubs, Small Trees	24" to 3' +
Trees	3' +

Figure 2: Minimum Depth of Media for Plants

## TYPICAL WEIGHTS OF MATERIALS

Material	lbs/ft3 Dry	lbs/ft3 Wet
water		62.428
vermiculite	5.75	24.5
perlite	6.5	32.4
sphagnum peat	9.6	70
ground bark	17	55
compost	32	82
expanded clay	40	54
pumice	40	47
Extensive media	42	65
expanded shale	44	58
expanded slate	48	57
lava rock	50	60
Intensive media	62	80
loam	80	120
sand	90	130
granite	170	170

\*Weights are not based on averages & may vary with product

Figure 3: Typical Material Weights

## Components Of Green Roof Growing Media

Uses for horticultural products and recycled products are surfacing. Even with all the choices, which will perform the best on a green roof can only be determined from long-term evaluation. Figure 3 gives some typical weight comparisons for materials used for horticultural applications.

### Organics

There has been much debate over the quantity of organics that makes up the media. In most cases the climate of the roof location should determine the amount of organics used. In arid climates decomposition may be slower or replenishing organics after decomposition may be practiced to maintain the water retention properties of the media. In humid regions over a short period of time, organics will decompose creating two specific problems. First, if the percent of organic matter is too high, the volume of mix decreases due to decomposition, requiring replacement due to the displacement of the media. Second, as the organics break down, the fines filter out down to the separation fabric. Once settled on the filter fabric, the organic fines decompose further creating a slime, which may impede the drainage causing the water to build

up in the media. This may create plant health problems and possibly increase the structural load. No more than 10% to 20% of the media should be organic in humid regions. Depending on local availability the type of the organics can vary including peat, rotted sawdust or bark, and composted organics.

Composted organics is a preferred source for the organic component in green roof system media because of its high nutrient and microbial count, and it is politically correct because of its recycling value. However care must be taken when selecting the source of compost; proper stability/maturity, particle size, and feed stock source of the product should be considered. Unfinished or unstable compost consumes nitrogen and oxygen; this can cause nitrogen deficiency and be detrimental to plant growth, even causing plant death. Excess soluble salts can be phytotoxic to plants. Manure composts tend to be higher in soluble salts than yard waste composts. Compost with soluble salts levels over 10 millimho/cm at 25 degrees C should be watered (leached) and retested before use. (4) This is because over time fertilizers will be applied to the media that may add to the levels. Caution must be exercised when using composted landscape wastes as it could possibly contain some residual herbicides that can inhibit plant growth. If during the composting process the thermophilic phase temperature is not sustained between 113 and 167 degrees F, the chances of weed seed contamination is high. Certain composts may be derived from feed stocks that may include bio-solids from municipal sewage treatment facilities. These sources may contain very fine particulates, heavy metals and pathogens. All composts should be tested using the US Composting Council's Test Methods for the Examination of Composting and Compost manual and any health and safety related parameters (state or federal) should be assured. Depending on the wastewater treatment facility biosolids may have a limited acceptance for horticultural use, especially green roofs including vegetable and fruit production. The fine particles tended to filter down through the mixture and cake up. Green roof media is designed to drain well and the affluent from the roof may be discharged into a creek or other body of water during which the heavy metals (copper, nickel, cadmium, lead, mercury, and zinc) that may be contained in the biosolids could leach out.

Peat moss is derived from sphagnum, which grows in bogs and is harvested. The harvesting of sphagnum peat has been the topic of many concerned environmentalists. Sedge peat or native peat consists mostly of partially decomposed sedges and grasses from bogs. Both types of peat have a pH between 3.3 and 3.5. Peat with a pH above 5.0 is rare. Peat has a very high water holding capacity and is difficult to dry, however when it is dry it is very difficult to wet. Most economical peat today has a very fine particle size. Peat is a good source of organic matter but it is low in nutrients and microbial population.

Milled softwood bark from products such as pine, fir, hemlock and cypress are used by the nursery industry throughout North America. Since softwood bark is low in cellulose and high in lignins it does not decompose rapidly, thus is a good source for the organic amendment in green roof media. Hardwood bark, sawdust or wood shavings should never be used in a green roof media unless fully composted. Because hardwood is high in cellulose and low in lignins they decompose quickly and will rob the plants of nitrogen. Unlike the peat products, the cation exchange capacity of bark improves with age. Bark should be milled to particle sizes less than ½ inch. Ground barks have low nutrient levels and a low pH. (5) I prefer to blend ground pine bark with compost to create a desirable organic component to a green roof growing media. Figure 2 shows some general comparisons between organic amendments.

## Lightweight Aggregates

As the main component of the media, the aggregates are the non-organic fragments that make up part of the mix. The aggregate in the media is what supports the plants and provides the pore space for air, water, and the exchange of gases. Because such a small amount of organics is recommended for green roof growing media the aggregate portion must serve additional functions for sustainability such as CEC, buffering, bulk density, drainage and when required, bio-remediation of contaminants. The size and type of aggregate will define how the media will function. "Since green roof media are highly aerated and contain relatively few fine particles (as compared to field soils), there is little if any capillary rise as there would be in a field soil. This makes sub irrigation of a green roof very inefficient." (6) Most manufactured lightweight aggregates are provided in many gradations, even gap graded if desired. The addition of aggregate fines or sand to the blend will help with water retention and some possible capillary action. In many parts of North America and Europe some type of lightweight aggregate can be obtained. If a manufactured lightweight aggregate is not available, products such as pumice, scoria (lava rock), or crushed roofing tile may be used. Crushed roofing tile has been used successfully in Germany as media in extensive systems for sedum. Roofing tile is fired differently than brick and cannot be interchanged with the same results. Calcined clay would be a better substitute than crushed brick. By-products such as blast furnace slag, bottom ash, and diatomite filter waste are not recommended.

Aggregates prepared by expanding, pelletizing, or sintering products such as clay, shale or slate is manufactured for the lightweight concrete industry. The most desirable lightweight aggregate is expanded shale, clay, or slate (ESCS) because of its availability, consistency and physical properties that meet the requirements of most green roof media specifications. In field soils nutrients are held for the plant by cation exchange and the capacity to hold cations is given as (CEC). Cations are positively charged ions like  $H^+$ ,  $Ca^{++}$ ,  $Mg^{++}$ , and  $K^+$  which are attracted to negatively charged soil particles.(7) ESCS aggregates replace clay in the soil and possibly most of the organics in the media, raising the importance of the role of the CEC to reduce leaching of nutrients from the media. While most natural clay based topsoil has adequate CEC, a green roof media mostly made up of coarse particles would have almost none. The CEC of the finer particles of ESCS average around 25.8 me/100g, providing an adequate substitute for natural clay soils for green roofs.

ESCS is a rotary kiln produced vesicular amorphous silicate particulate material. It is a highly porous, low-density material and depending on the product, specific gravities range from 0.8 to 2.4 , and a dry/loose unit weight of approximately 35 to 60 pounds per cubic foot, (561 to 962 kg per cubic meter). The pre-sized raw shale, clay or slate used to produce ESCS is fired in the kiln at a temperature between 1800° F (982° C) and 2200° F (1205° C). As it exits the kiln the material is sterile, inert, and ceramic. Some crushing may be performed to facilitate final screening in a screening system. ESCS is generally neutral in pH although the pH can vary somewhat higher to 8.5 depending on the raw material and the fuel used for processing. In humid areas utilizing extensive sedum green roofs, media with a higher pH can be beneficial to buffer the lower pH rainwater. Test Method C 29/C 29M determines density (loose unit weight). Test Method C127 may determine the absorption after soaking the material. The particle distribution may be determined with the appropriate sieves as stated in Specification C136. The ESCS may be sampled in accordance with Practice D 75. (8)

ESCS is generally used in green roof systems as the mineral component of the media mix, as a granular drainage material, or as a media alone with no amendments. It is available throughout the United States and in a few countries overseas as shown in Figure. 3. The hydraulic conductivity of the ESCS will differ depending on type and gradation. The gradation can vary from ¾ inch (1.9 cm) to a fine sand like material. The media may require a blend of different sizes of ESCS with or without sand and/or an organic component depending on whether the application is for an *Intensive or Extensive* green roof. Variations in the media can be obtained by adjusting the gradation of ESCS to meet the desired porosity or weight requirement. The main adjustment that needs to be addressed is a correction for the weight and volume relationship of ESCS fines, that is, the minus No. 4 (4.75 mm) sieve size to a similar size of sand. The oven-dry or saturated surface dry/loose unit weight tests (see Test Method C 29/C 29M) can be performed to establish the weight-volume relationship. (9) Care must be taken to specify what C 29/C 29M testing procedure 9.0 is to be used for ESCS fines (rodding 10.1, jiggling 11.1, or shoveling 12.1). Using the shoveling procedure to determine loose bulk density may result in the sample weighing less per volume moist than it will when dry because moisture tends to cause bulking of the ESCS fines that creates larger air pockets in the sample. Typically, a loose cubic foot of ESCS fines will weigh approximately from 35 pounds per cubic foot (560 kg/m3) to 65 pounds per cubic foot (1120 kg/m3) depending on the source. Absorption of ESCS varies with the source, but is usually 9% to 35% of the oven-dry loose unit weight. Because of the absorption differences between the types of ESCS, determining the amount of water release from the particles of ESCS may be important when specifying certain plant species. Care must be taken not to have the media hold too much moisture or pull needed water away from the roots. The absorption (ASTM C127) and the particle size distribution (ASTM C136) of ESCS can determine the porosity of the media. Providing good drainage and encouraging deep roots is essential when developing a green roof planting media.

Some of the properties of ESCS are:

1. Lightweight 40 to 65 lbs. Per cubic foot, will not float or blow away
2. pH 7.0 to 9.0
3. CEC 5.0 to 43.0 meq/100g
4. Will not decompose or degrade by freezing and thawing
5. Good water holding capacity with lower absorption and higher water release
6. Open cells hold water and closed cells provides the lightweight characteristic.
7. Bulk specific gravity ASTM C127 1.60

Perlite and vermiculite are natural inorganic materials that have been heated to expand providing pore space. Both are very soft and are not recommended for use in green roof media in quantities over 20% of the total mix. They can breakdown from freezing and thawing and tend to float or blow out of the mix. Other products worth testing are: calcined clays (excluding kitty litter), pelletized diatomaceous earth, Isolite, and other soil-less media using compressed composites or rockwool fiber.

### ESCS Manufacturing Locations

#### North America

Alabama	Maryland
Alberta, Canada	Missouri
Arkansas	New York
Colorado	North Carolina
California	Ohio
Indiana	Oklahoma
Kansas	Texas
Kentucky	Utah
Louisiana	Virginia

#### South America

Caracas, Venezuela

#### Europe

Belgium	Norway
Germany	Russia
Italy	Spain

#### Asia

Chiba-ken, Japan

Figure 4: ESCS Manufacturing Locations

## **Sand**

Sand alone, or even with some organic is unable to retain enough nutrients to sustain the plants without scheduled irrigation and fertilization. This is why golf course putting greens must be irrigated and fertilized regularly. Usually sand, if used at all, is only 30% of an extensive blend and no more than 50% of an intensive media. More often ESCS has been graded down to particle sizes to replace the sand in the media. Finer ESCS increases the water holding capacity and CEC of the media. Coarse sand is preferred with no particle larger than 2mm in diameter. Particle size should range be between .25mm to .75mm, fines below 10 mm should be less than 10% of the mix. To be safe the sand should meet USGA root zone specifications for putting greens. Field or creek sand should be avoided unless sterilized or water separated, otherwise you may have a lovely crop of weeds on your rooftop. Sand should meet the following criteria:

1. Weight wet 110-130 lbs. per cubic foot
2. Must be non-calcareous (not chalky)
3. Should meet USGA particle size requirements for putting green construction
4. Has no or negligible 0-4 meg/100g CEC
5. Should have a total pore space volume between 12 and 25% capillary and 15-30% non-capillary
6. Bulk density 1.25 to 1.60 grams per cubic cm. (used to calculate porosity)

## **Project Management**

As designers we are expected to be competent in the design of plans that the contractor is expected to implement as specified. To design and specify without following proper horticultural practices may be considered by some to be incompetent, especially to a competent landscape contractor. On the other side of the fence, I have been discouraged many times by the compulsion by some landscape contractors to not follow specifications. This action may bite them back professionally and legally. It is especially important to follow specifications for green roof systems; mistakes can be catastrophic because contrary to popular belief, everything that goes up does not necessarily come down. The solution is for the designer to get paid to manage the green roof portion of the project separate from the general contractor. Final green roof work can be a separate bid item away from the general contractors budget. Granted, this sometimes can open up a new can of worms with scheduling, but with this, someone other than the owner can never assume the designer's control.

## **Blending**

Blending the media components on the construction site is not recommended because the possibility of contamination. Companies experienced with blending media almost always perform these services at their own facility and transport finished product to the site. An experienced operator must perform the blending operation to insure that the ratio of the individual components in the final mix is correct. Mixing equipment may vary from facility to facility. Some use high tech blending equipment with hoppers and belts, while others are talented enough to judge quantities just using loader buckets. A concrete slab is preferred when mixing the materials to avoid contamination. Working with expanded lightweight aggregate (ESCS) is adventitious during the blending process. When saturated with water ESCS actually allows the other components to adhere preventing separation during transport

and placement. Make sure the equipment is pressure washed prior to handling media to prevent weed seed contamination.

The acidity or alkalinity of the media is important. The pH must be within a range allowing green roof plants to take up nutrients from the media. For long-term plant health, the pH should be relatively stable especially in the eastern US where acid rains can significantly reduce the pH of the media. In parts of the Northeast, rain pH is as low as 4.9. If the base mineral of the roof medium has a relatively high pH, then the acid storm water exiting the roof should be neutralized. Penn State experiments have shown that when rainwater migrates through an expanded clay roof, the pH is moderated close to neutral, pH7. (10 ) With its pH ranges of 7.0 to 9.0, ESCS is very beneficial for buffering. This is especially good for sedums. Excess acidity may be corrected by the application of lime dust. Excess alkalinity may be corrected by the application of sulfur or other suitable acidifying compounds. The nutrient content of the media is important and the chemicals usually evaluated are nitrogen, phosphate, potassium and some trace elements. However, except to correct pH, I feel to amend the media during the blending process is unreasonable and not economical. First, the media is often placed on the roof several months before the plant material is installed, crane availability and construction schedules often dictate placement. Second, because the media drains so well, pre-blended fertilizer located within the lower profile will be leached out and be wasted before the new roots reach it. Nutrient deficiencies may be corrected by using slow release fertilizers at the time of planting.

## **Placement**

Especially in tight spots, placing the media on the rooftop can be challenging. Conveyors, cranes, lifts, blowing machines, elevators, packaging, and yes, even helicopters have been utilized. Care must be taken because of weight restrictions and safety issues. When stockpiled, protect the media from absorbing excess water and from erosion at all times. Do not store materials unprotected from large rainfall events. Do not deliver or place the media in frozen, wet, or muddy conditions. Material should be at or near optimum compaction moisture content as determined by AASHTO T 99 (ASTM D 698). Do not place materials that are excessively moist. Do not allow excess water to enter site prior to compaction. If water is introduced into the material after stockpiling, allow material to drain or aerate to optimum compaction moisture content. After placement onto the roof, preset the media by thoroughly watering the entire planting area. Fill settled low areas with the media and repeat the compaction and filling process until settlement ceases. When handling materials, operating tools and equipment, protect the media from displacement by laying down planking or plywood as required for protection.

## **Value Engineering**

We must keep an eye on what goes up on the roof. Contractors not familiar with the importance of the growing media may be talked into a substitution that will only satisfy the lawyers. This brings us to an oxymoron... "value engineering" or what I like to call it "de-value engineering". In my opinion, the single most annoying and difficult part of protecting the design intent of a project occurs after the bidding process. It starts when the general contractor mutters the oxymoron "Value Engineering". This by far is the dirtiest word in the business. It doesn't matter who utters the phrase; it always lands in the lap of the green roof designer. Why is this? It is very simple; the budget is blown at the end of the project not in the beginning. The growing media and planting is almost always the last phase on the critical path to completion. A talented designer can work with the project owner and work out design issues to reduce costs without totally

jeopardizing the intent of the design. However in the real world, we as designers are usually the last ones to find out that their designs have been diminished in the back office of the construction trailer by the sub-contractor and the general contractor. When the designer finds out what has happened, he or she better be ready to whip out a very convincing rejection letter to squash the attempted sabotage.

As an insider, I can give you some insight on how value engineering is sometimes abused. It usually starts early in the game, during the bidding process, and with no doubt the lowest bidder has already devised a plot to undermine the specifications and pad the low bid. They usually are the ones that were calling vendors for material prices the final day before the bid letting or just after when they are told they left something out. As the overruns pile up during construction, the budget starts to get squeezed. One day, when the weekly job meeting begins, the construction superintendent asks for some "value engineering" suggestions for the remaining items on the punch list. Of course our lowest bidder has some wonderful substitutions to suggest. He then pulls it out and shows everyone at the meeting how it can replace the more "expensive" specified product with another at a much lower cost. Now here is the secret that the shafted specified vendor will eventually find out: The low bidding sub-contractor, having already securing the best deal on the substitution product, knows it's very late in the game, now can mark up the price twice as much than when he bid it under competitive conditions, thus making more money by "de-valuing" the job.

Now that we are savvy of the practice, how do we control it? It is up to us as professionals to challenge every modification made to our designs without our seal of approval. Most of the time, the offended vendor who just unfairly lost out to an unworthy competitor alerts us. The folks who get hurt the most by this practice are the good contractors who bid the projects to specifications, as they never had the opportunity to win the bid fairly. It seems no matter what the project management relationship is between the designer and the general contractor, the budget rules. When this happens late in the project, proper communications between the parties do tend to drift. Sometimes the "approved equal" specification is ignored completely. Budget issues will always include the green roof plan, however, the designer and the licensed installation contractor can go over the line items together and work out the best way to take the "de" out of "value engineering". Everyone with professional integrity and the proper knowledge to stay current will benefit. The long-term results will benefit everyone.

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## **15D**

***“Dissolved Phosphorus Retention of Light-Weight  
Expanded Shale and Masonry Sand  
Used in Subsurface Flow Treatment Wetlands”***

**Forbes M.G., Dickson K.R., Golden T.D., Hudak P. and Doyle  
R.D. (2004) Environ. Sci. Technol. 38:892-898**

# Dissolved Phosphorus Retention of Light-Weight Expanded Shale and Masonry Sand Used in Subsurface Flow Treatment Wetlands

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Using surface flow constructed wetlands for long-term phosphorus (P) retention presents a challenge due to the fact that P is stored primarily in the sediments. Subsurface flow wetlands have the potential to greatly increase P retention; however, the substrate needs to have both high hydraulic conductivity and high P sorption capacity. The objective of our study was to assess the P retention capacity of two substrates, masonry sand and light weight expanded shale. We used sorption/desorption isotherms, flow-through column experiments, and pilot-scale wetlands to quantify P retained from treated municipal wastewater. Langmuir sorption isotherms predicted that the expanded shale has a maximum sorption capacity of 971 mg/kg and the masonry sand 58.8 mg/kg. In column desorption and column flow-through experiments, the masonry sand desorbed P when exposed to dilute P solutions. The expanded shale, however, had very little desorption and phosphorus did not break through the columns during our experiment. In pilot cells, masonry sand retained (mean  $\pm$  standard deviation)  $45 \pm 62$  g P/m<sup>2</sup>/yr and expanded shale retained  $164 \pm 110$  g P/m<sup>2</sup>/yr. We conclude that only the expanded shale would be a suitable substrate for retaining P in a subsurface flow wetland.

## Introduction

Constructed wetlands were initially believed to provide efficient, long-term retention of phosphorus (P) from polluted waters until it was realized that newly constructed wetlands

quickly become saturated with respect to P (1, 2). It is now understood that long-term P retention in wetlands is a challenge, especially when the dominant form of P is dissolved. Many municipal, agricultural, and stormwater discharges have large proportions of total P in the dissolved form. The greatest capacity for long-term storage of P in surface water wetlands is in the substrate through either peat building, which is the dominant process in wetlands without mineral soils, or adsorption to mineral sediments (3). Richardson and Craft (2) estimated a global average of P burial through peat accretion at 0.5 g P/m<sup>2</sup>/yr. At this rate, 683 acres (276 ha) would be required to treat 1 million gallons per day (3785 m<sup>3</sup>/d) of wastewater with an initial P concentration of 2 mg/L to a final effluent concentration of 1.0 mg/L. There is a need, therefore, to improve the areal efficiency of P retention in constructed wetlands. Our study estimates areal P retention utilizing substrates with high sorption capacity and high hydraulic conductivity.

Phosphorus sorption in freshwater wetland soils is usually controlled by iron (Fe) and aluminum (Al) in acidic soils and calcium (Ca) and magnesium (Mg) in alkaline soils (3–5). Phosphorus may be removed from solution by nonspecific physical adsorption (ion exchange), specific chemical adsorption/precipitation and complexation (4). The first mechanism, ion exchange, is driven by the surface charge and surface area of particles. Physically adsorbed phosphate is not held as tightly by the soil as it can be desorbed with water. The second mechanism, chemical adsorption, involves ligand exchange. This occurs when the oxygen atoms in the phosphate ions displace the surface hydroxyl groups and water molecules coordinated with Fe and Al (6).

Adsorption of phosphate by silicate clay minerals appears to occur in a similar manner, with phosphate bonding to the Al atoms exposed at the edges of the clay particles and the substitution of phosphates for silicate in the clay matrix comprising the primary mechanisms of phosphorus–clay interaction (7).

Both physical and chemical sorption processes can be rapid, occurring within minutes of mixing. Slower reactions continue to remove phosphate from solution for periods of from several days to several months. Continued removal of phosphate from solution has been attributed to physically adsorbed P forms shifting to chemically adsorbed forms, the diffusion of phosphate adsorbed on the surface of structurally porous oxides of Fe and Al to positions inside the matrix, and the precipitation of crystalline Fe, Al, and Ca phosphates (8).

Wetlands with highly sorptive soils, however, may retain low quantities of P due to inadequate sediment–water contact. This applies to surface water wetlands with high water depth and systems with substrates of low hydraulic conductivity. For example, the chemistry and high surface area of many mineral clays contributes to their high P sorption capacity, but their low hydraulic conductivities limit sediment–water contact and thus their opportunity to retain P is severely reduced.

The use of various substrates in subsurface flow wetlands for P sorption capacity has been investigated in both laboratory experiments and small-scale constructed wetlands (8–12). Several studies have assessed the 24-h P sorption capacity of various light-weight aggregates, slags, and sands. Zhu et al. (13) found that two iron-rich sands from Montana had an average P sorption capacity of 441 mg/kg, whereas P sorption capacity of various aggregate materials ranged from 37 to 3460 mg/kg. Few studies, however, have examined P retention of media under both batch loading (sorption

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isotherms, and continuous loading (pilot cells). The purpose of this research was to assess P retention by two media, masonry sand and expanded shale (manufactured by Texas Industries, Streetman, Texas) in a subsurface flow constructed wetland and compare it to P retention in an adjacent surface flow wetland with native soil. We also compare the sorption capacity of these two materials as determined by isotherm experiments to their performance in both flow-through column experiments and pilot-scale constructed wetlands.

## Methods and Materials

**Site Description.** The project is located at the Pecan Creek Water Reclamation Facility (PCWRF) in Denton, Texas. Effluent from PCWRF, treated by activated sludge, was diverted to the project area. During the study period, mean ( $\pm$ standard deviation) total suspended solids and total P of the effluent were 1.81 ( $\pm$ 1.35) and 1.85 ( $\pm$ 0.95) mg/L, respectively.

**Physical Characteristics.** Expanded light-weight shale utilized in this study is manufactured from shallow shale deposits mined from a location near Streetman, Texas. The shale is sorted by size and then fired for 30–40 min in a rotary kiln to temperatures of approximately 2000 °F (1093 °C). The result is a stable, porous material with little organic material. The manufacturer reported the following chemical composition for their expanded shale:  $\text{Al}_2\text{O}_3$  15.86%,  $\text{Fe}_2\text{O}_3$  5.80%,  $\text{CaO}$  1.44%, and  $\text{MgO}$  1.68%; thus, Al and Fe are major components of this material. Masonry sand is a readily available, fine-grained sand commonly used as an ingredient in mortar and plaster and as fill during various construction activities. It has been washed to remove clay, silt, and organics. Particle size distribution and soil porosity of masonry sand and expanded shale were determined by standard procedures (14). The hydraulic conductivity of masonry sand and expanded shale was determined in the laboratory using a Soiltest K-605 constant head permeameter. Hydraulic conductivity ( $K$ ) was calculated using Darcy's law (14).

**Sorption Isotherms.** Sorption isotherms express the variation of specific adsorption with equilibrium concentrations of adsorbate in bulk solutions at constant temperature (15). There are several relationships used to describe the experimental isotherm. The Langmuir model (eq 1) describes deposition of a single layer of solute molecules on the surface of the solid and thus may be used to predict the maximum sorptive capacity of the sorbent for the given sorbate at the experimental temperature.

$$C_e/(x/m) = (1/ab) + (C_e/b) \quad (1)$$

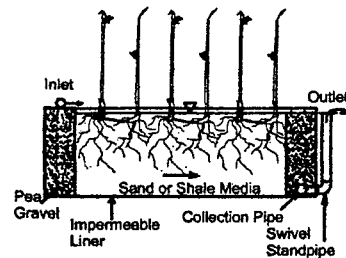
where  $x/m$  is the mass of solute adsorbed per gram of sorbent at concentration  $C_e$  (g/kg),  $a$  is the adsorption constant related to the binding energy,  $b$  is the mass of solute adsorbed in forming a complete monolayer on the sorbent surface (L/g), and  $C_e$  is the concentration in solution at equilibrium (mg of P/L).

Barrow (16) examined phosphate sorption over much longer periods of time and modified the empirical Freundlich equation to describe the process (eq 2).

$$X = kC_e^a t^b \quad (2)$$

where  $X$  is the mass of solute adsorbed per gram of sorbent at concentration  $C_e$  (mg/g),  $C_e$  is the concentration in solution at equilibrium (mg of P/L),  $t$  is the time, and  $k$ ,  $a$ , and  $b$  are constants.

The effects of time ( $t$ ) and initial phosphate concentration ( $C_0$ ) on sorption for both media were modeled using the linear form of eq 2.



**FIGURE 1.** Cross-sectional view of one pilot cell. Cells are 3 ft (0.9 m) high, 4 ft (1.2 m) wide, and 8 ft (2.4 m) long. Separate inlet and outlet compartments approximately 1 ft (30.5 cm) in length were filled with pea gravel to promote even distribution of wastewater.

Sorption isotherms in this study were constructed according to methods described in OECD (17). Solutions were analyzed for soluble reactive phosphate (SRP) using the ascorbic acid method. Two types of isotherm experiments were conducted. The first used low initial concentrations of P (0, 0.5, 1.0, 2.0, and 3.0 mg of SRP) to assess sorption at the low levels typically observed in wastewater effluents. These low-level experiments were repeated at 3, 10, 30, 100, and 300 h to estimate the rate of sorption. The second experiment used high P concentrations in the range 0, 20, 40, 80, 160, and 320 mg of SRP so that comparisons to other materials could be made. These high P experiments were also used to assess P desorption in the two medias. Desorption was measured by immediately adding fresh, dilute solution to the media, shaking for 24 h, and analyzing the filtrate. Three desorptions were performed, the first two with solutions of fresh wastewater effluent (0.4 mg of SRP) and the third with deionized water.

The effect of pH on sorption to expanded shale was examined by constructing isotherms with pH-buffered phosphate solutions. Three pH levels, 4–5, 6–7, and 8–9, were examined using initial SRP concentrations of 0, 3, 10, 30, and 100 mg/L. Two pH levels, 4–6 and 8.5–9.5, were examined using initial SRP concentrations of 0, 0.5, 1.0, 2.0, and 4.0 mg/L.

**Column Flow-Through Experiments.** Phosphorus breakthrough curves were used to quantify P sorption under continuous loading. Four columns were constructed of 4-in.-diameter polyvinyl chloride (pvc) pipe and packed with masonry sand or expanded shale. Secondary treated effluent entered the bottom of the columns under constant pressure and exited near the top. Sampling of flow-through experiments was conducted by taking grab samples of inflow and outflow solutions over a period of several days. The flow rate ( $Q$ ) of each column was measured manually. Samples were analyzed for pH, conductivity, temperature, and SRP; the ratio of outflow concentration ( $C_e$ ) to inflow concentration ( $C_0$ ) was plotted against the cumulative volume of wastewater flowing through the column(s). Mass of P retained was determined by integration of these plots.

**Pilot Cells.** Although flow-through columns have the advantage of examining P sorption under nearly ideal hydraulics and continuous loading, they do not simulate the conditions of a full-scale treatment wetland. Pilot cell studies were designed to include the effects of P cycling between biotic and abiotic compartments and provide a more realistic prediction of long-term P retention. Subsurface flow pilot cells were built from two plywood structures divided into three cells by adding internal walls. The cells were 3 ft (0.9 m) high, 4 ft (1.2 m) wide, and 8 ft (2.4 m) long and lined with 0.045-mm-thick rubber pond liner (PondGard, Swanton, Ohio) (Figure 1).

Each cell was planted with 30 plugs of *Schoenoplectus californicus* (C.A. Mey). Each cell had an inlet meter that recorded cumulative inflow; however, these meters failed

**TABLE 1. Physical Characteristics of Masonry Sand and Expanded Shale**

characteristic	masonry sand	expanded shale
effective size ( $D_{10}$ ) ( $\mu\text{m}$ )	110	720
uniformity coefficient	1.4	2.3
density ( $\text{kg}/\text{m}^3$ )	1670	728
porosity ( $n$ )	0.304	0.594
hydraulic conductivity ( $K$ ) (m/d)	17.3	92.2
pH of 10 g of material in 50 mL of water	8.28	9.38

during the study after which manual measurements were substituted. Cells A, B, and C contained masonry sand and cells X, Y, and Z contained expanded shale. Approximately twice monthly, grab samples were collected from one of the cell inlets ( $P_{in}$ ) and all six pilot cell outlets ( $P_{out}$ ). Samples were analyzed for SRP, pH, temperature, and conductivity. Every fifth sample was duplicated. We estimated P retained by the sand or shale by multiplying the difference between  $P_{in}$  and  $P_{out}$  by the volume of water treated.

**Surface Flow Wetland.** To compare our subsurface flow pilot cells to a surface flow wetland, we also monitored an adjacent, 2-acre treatment wetland. Beginning in November of 2000, we collected grab samples approximately halfway through the wetland's flow path ( $Wet_{Mid}$ ) and at the outfall ( $Wet_{out}$ ). This small wetland, which was originally constructed to address toxicity issues, receives the same treated effluent as the flow-through columns and pilot cells. Hemming (18) estimated the wetland's nominal hydraulic retention time to be approximately 4.3 d. The wetland had water depths of approximately 30 cm and was heavily vegetated, primarily with *Typha* sp. (cattails), *Lemna* sp. (duckweed), *Pontederia cordata* (pickerelweed), *Ludwigia* sp. (water primrose), and *Schoenoplectus* sp. (bulrush).

## Results and Discussion

**Physical Characteristics.** Expanded shale had a larger effective size, a higher hydraulic conductivity, and greater porosity than masonry sand (Table 1). The higher porosity in the expanded shale probably stems from internal micropores within individual particles as well as greater voids between neighboring particles due to their rectangular shape. Micropores in the shale probably contribute to a larger surface area than that of masonry sand, despite sand's smaller particle size.

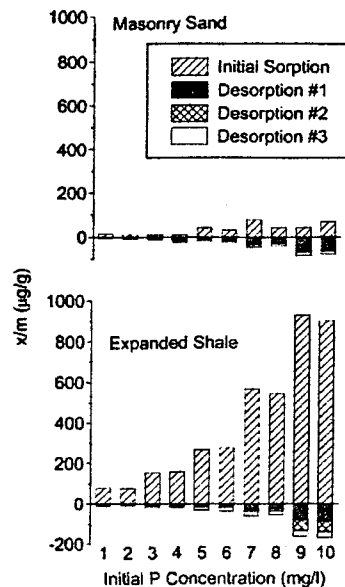
**Sorption Isotherms.** The expanded shale had a sorption capacity, as estimated by the Langmuir model, of 971 mg/kg, compared to 58.8 mg/kg for masonry sand. Furthermore, in desorption experiments the expanded shale was found to release relatively little of the sorbed phosphate, while the sand released most or all of the sorbate (Figure 2). Masonry sand desorbed between 65 and 120% of P originally sorbed in the high-concentration experiment, compared to expanded shale which desorbed between 10 and 19% of previously sorbed P.

We observed additional P sorption in both materials with extended shaking time. Expanded shale, for example, reduced P levels from 3 to 0.49 mg/L in 3 h and to 0.016 mg/L in 300 h (Figure 3). Multiple regression on the log-transformed data yielded the following models:

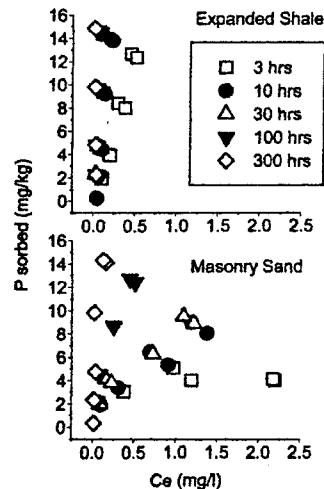
$$\text{masonry sand } x/m = 0.01C^{0.796}P^{0.137} \quad (p < 0.0001; R^2 = 0.923)$$

$$\text{expanded shale } x/m = 0.005C^{0.990}P^{0.014} \quad (p < 0.0001; R^2 = 0.978)$$

Others have observed that the amount of phosphorus removed by soils receiving long-term wastewater applications

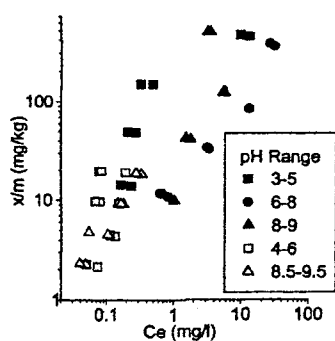


**FIGURE 2. Initial sorption with concentrations of phosphorus (P) ranging from 20 to 320 mg/L, followed by two desorptions with wastewater (#1 and #2) and one desorption with deionized water (#3).**



**FIGURE 3. Sorption isotherms for masonry sand and expanded shale conducted for increasing equilibrium times of 3, 10, 30, 100, and 300 h. The initial phosphate-P concentrations for each isotherm were 0.5, 1.0, 2.0, and 3.0 mg/L.**

was many times greater than the amount predicted using 24-h sorption experiments (19, 6). Short-term, or rapid sorption, may involve interactions with easily accessible surface minerals such as precipitation, anion exchange, and the replacement of  $-\text{OH}_2$  or  $-\text{OH}$  groups with phosphate ions (20, 21). In expanded shale, additional sorption may result from transport of phosphate ions into less accessible sorption sites located within micropores. Longer term P retention in many soils may be enhanced by the increasing insolubility, over time, of compounds formed during rapid sorption (20). In addition, longer term sorption rates are influenced by diffusion of phosphorus through the metal phosphate precipitate to the unreacted metal oxide surface, which is a function of the phosphorus concentration gradient between the bulk solution and the interface between the metal oxide and the metal phosphate (22). In sorption isotherm experiments conducted by Barrow (16), solution P concentrations continued to decrease for at least 1000 days.



**FIGURE 4.** Sorption isotherms for expanded shale conducted at pH values ranging from 3 to 5 to 8.5–9.5. Initial SRP concentrations were high (solid symbols, 3, 10, 30, and 100 mg/L) and low (open symbols, 0.5, 1, 2, and 4 mg/L).

Barrow (16, p 735) concluded that "the initial reaction with the surface of a soil particle induces a diffusion gradient toward the interior of the particle and begins a solid-state diffusion process."

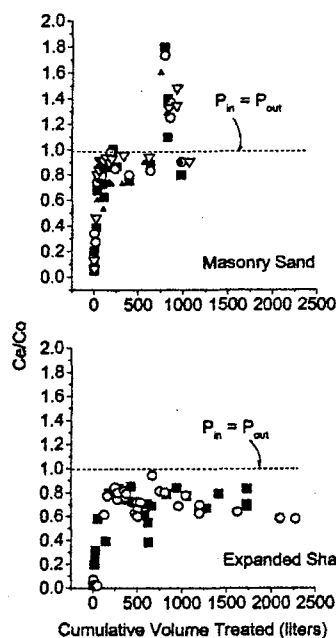
Masonry sand also continued to remove P with increasing shaking time, but did not remove as much P as expanded shale. Masonry sand reduced P from 3 to 2.19 mg/L in 3 h, and after 300 h, P was reduced to 0.145 mg/L (Figure 3).

Application of these results to wastewater treatment operation suggest that an expanded shale system receiving wastewater with 3.0 mg/L and an effluent target of 0.5 mg/L would be most efficient with a hydraulic retention time as short as 3 h. On the other hand, a system using the masonry sand would require 100 h to achieve an effluent with 0.5 mg/L. Further increases in retention time would not substantially improve sorption in either material and could result in desorption in masonry sand. These results led us to design our pilot cells with the shortest possible hydraulic retention time.

In unbuffered isotherm experiments, expanded shale typically raised the pH to 8 and above in a 24-h period. This was most likely due to the presence of soluble hydroxides on the surface of the shale. During pH-controlled experiments sorption was highest at pH 3–4 for solutions with an initial [SRP] of 30 mg/L or less (Figure 4), suggesting P association with soluble  $Al^{3+}$ . At pH 8–9, formation of various calcium phosphate compounds is favored, depending on [SRP], ionic activity, temperature, and other factors (21). Sorption was highest at high pH in solutions with initial [SRP] of 0.5, 1.0, and 100 mg/L. Enhanced P retention at high pH and high [SRP] may be a result of the formation of dicalcium phosphate ( $CaHPO_4 \cdot 2H_2O$ ), which is predicted at pH 8–9 with [SRP] = 100 mg/L, but not at [SRP] = 30 mg/L (21). This precipitate may be redissolved if pH decreases, but in time (i.e., 3–6 months) it is typically replaced by more stable and less soluble calcium phosphates minerals such as octacalcium phosphate [ $Ca_8H(PO_4)_3$ ] and hydroxyapatite [ $Ca_5(PO_4)_3(OH)$ ] (23). At lower [SRP] representative of municipal and agricultural wastewaters (0.5–4.0 mg/L), all of the pH solutions reduced [SRP] to below 0.5 mg/L.

The lowest P retention occurred at pH 6–8, the pH most likely to be encountered in natural and wastewater environments. This is a result of increased solubility of Fe, Al, and Ca phosphate compounds at this pH range. At moderate pH ranges, however, interactions between phosphate and silicate compounds occur (20). Silica is a primary component of both masonry sand and expanded shale.

**Flow-Through Column Experiments.** In flow-through columns experiments, P retention was also higher in columns containing expanded shale. In the four sand columns, breakthrough occurred at approximately 250 L (Figure 5), followed by desorption of previously sorbed P between 750



**FIGURE 5.** Phosphorus breakthrough in columns with masonry sand or expanded shale receiving continuous flow of treated effluent. The broken line ( $C_t/C_0 = 1$ ) represents the breakthrough point.

and 1000 L. Additional sorption occurred after 1000 L. Net sorption by masonry sand was essentially zero because the sand desorbed all of the P that was initially sorbed. The desorption is based on three samples after incoming P concentrations dropped from 2.62 to 1.54 mg/L and remained below this level. When  $C_0$  increased again, sand in the column sorbed added P. The observed desorption was consistent with desorption in high-concentration isotherm experiments; that is, masonry sand easily desorbs previously sorbed P when exposed to more dilute P solution. It appears that P is only loosely sorbed to the sand surface, probably through ion exchange, which is easily reversed. The pH of sand columns ranged from 7.5 to 8.4 during the experiments, compared to pH 6.7–7.8 of the inflow.

Initially, expanded shale columns followed a P retention pattern similar to the masonry sand (Figure 5), that is, an initial period of high P retention and a rapid approach toward saturation. Easily accessible sorption sites on the exterior of the particles are probably being utilized during this phase. Unlike masonry sand, however, breakthrough did not occur in either shale unit; instead, the rate of P removal from solution decreased but then remained more or less stable for the remainder of the experiment. This longer term phase may reflect molecular diffusion of P to less accessible sorption sites located within micropores. Expanded shale columns had pH values ranging from 9.6 to 7.6, compared to pH 7.0–8.0 of the inflow. Expanded shale increased the pH of the incoming wastewater more than 2 units during the first half of the experiment, but this increase fell to approximately 1 pH unit increase by the end of the experiment. The decreasing pH during the second half of the experiment may have contributed to sustained P retention as association with hydrous oxides of Al and Fe, and silicates, would be favored.

The two expanded shale units retained 45% and 40% of incoming wastewater SRP. However, total mass of SRP retained by Columns 1–2 (407 mg/kg) was much higher than that retained by Columns 3–4 (135 mg/kg) due to greater volume of wastewater treated (despite our efforts to maintain similar flow rates). Of interest is the fact that substantially higher flow rates through Columns 1–2 did not diminish the percentage of P retained.

**TABLE 2. Characteristics of Three Pilot Cells (A, B, and C) Contained Masonry Sand and Three (X, Y, and Z) Contained Expanded Shale. All 6 Pilot Cells Had Approximately 90% Coverage with *Schoenoplectus californicus***

	masonry sand (A,B,C)	expanded shale (X,Y,Z)
substrate volume (L) per unit	1930	1930
mass substrate (kg) per unit	3220	1400
pore volume (L) per unit	587	1146
approximate head (cm)	15	15
days operated	392	416
estimated quantity wastewater treated (m <sup>3</sup> )	430	490
estimate hydraulic loading rate (cm/d)	46	55

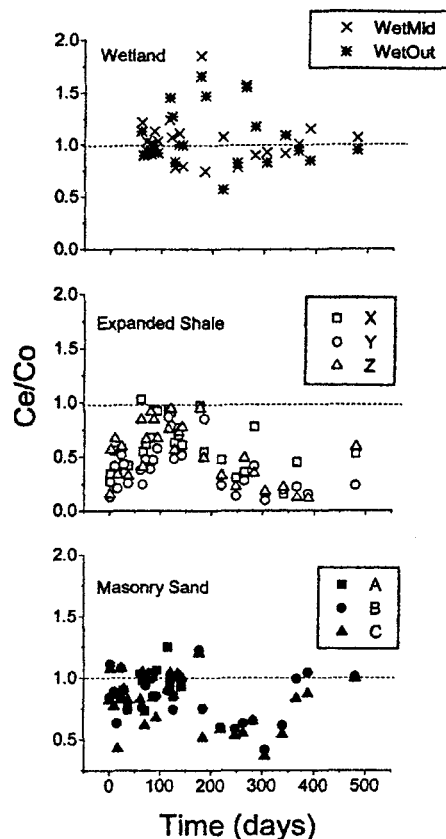
**Subsurface Flow Pilot Cells.** Pilot cells were operated and monitored from September 2000 to January 2002; however, Cell A developed a leak early in the study and was taken off-line. Selected physical and operational parameters of pilot cell units are provided in Table 2. Meters used to measure flow rates into the cells failed after several months and manual flow measurements were taken for the remainder of the study. The values of incoming [SRP] ( $P_{in}$ ) during the study ranged from 0.364 to 2.25 mg/L (Table 3) with the lowest concentrations occurring after periods of heavy rain. Expanded shale had the highest percent SRP retention (51%); masonry sand averaged only 14%. Expanded shale also retained SRP regardless of season, whereas masonry sand exported SRP occasionally, primarily during the rainy season when incoming [SRP] was very dilute (Figure 6). This is consistent with observed desorption by masonry sand in isotherm and column experiments.

Effluent from the three shale cells had the lowest mean SRP concentrations ( $P_{out}$ ), whereas the highest were from the two surface wetland locations (Figure 7). Mean  $P_{out}$  from the pilot cells X, Y, and Z were not significantly different from each other but were significantly less than mean  $P_{out}$  of masonry sand, both surface water wetlands, and  $P_{in}$  (Tukeys multiple range test,  $\alpha = 0.05$ ,  $P_{in} = \text{Wet}_{out} = \text{Wet}_{mid} = A = B = C > Z = Y = X$ ).

Expanded shale sorption capacity showed no distinct trend toward saturation or desorption, which was also consistent with isotherm and column studies. By contrast, the surface water wetland appeared to export P randomly (Runs test,  $\alpha = 0.05$ ), suggesting that the surface water wetland is saturated with respect to P.

**TABLE 3. Means, Standard Deviation, and Range of SRP Concentrations, delta P ( $P_{in} - P_{out}$ ), and  $C_e/C_0$  for Pilot Cells, Inflow, and Wetland Stations**

	inflow	pilot cells						adjacent wetland	
	$P_{in}$	A	B	C	X	Y	Z	Wet <sub>mid</sub>	Wet <sub>out</sub>
		Soluble Reactive Phosphorus (SRP) (mg/L)							
mean (mg/L)	1.54	1.40	1.29	1.215	0.82	0.58	0.76	1.57	1.51
standard deviation	0.455	0.309	0.435	0.429	0.397	0.244	0.392	0.536	0.391
grand mean, S.D. and <i>n</i>	N/a	1.28 + 0.411 ( <i>n</i> = 73)			0.703 ± 0.366 ( <i>n</i> = 86)			1.54 + 0.465 ( <i>n</i> = 44)	
minimum	0.36	1.00	0.45	0.31	0.22	0.21	0.23	0.45	0.61
maximum	2.35	1.86	2.05	1.92	1.86	1.19	1.67	2.30	2.26
<i>n</i>	29	15	29	29	29	29	28	22	22
		$P_{in} - P_{out}$ (delta P) (mg/L)							
mean (mg/L)	N/a	0.09	0.25	0.3272	0.72	0.96	0.79	0.00	-0.06
standard deviation	N/a	0.186	0.344	0.383	0.539	0.631	0.587	0.344	0.280
grand mean, S.D.	N/a	0.25 + 0.343			0.84 + 0.563			-0.029 ± 0.312	
minimum	N/a	-0.272	-0.162	-0.105	-0.059	-0.826	0.021	-0.805	-0.851
maximum	N/a	0.437	1.259	1.374	1.857	2.063	1.991	0.847	0.464
<i>n</i>	29	15	29	29	29	29	28	22	22
		$C_e/C_0$							
grand mean and S.D.	N/a	0.855 ± 0.199			0.492 ± 0.26			1.062 ± 0.273	



**FIGURE 6. Ratio of effluent soluble reactive phosphate (SRP) to incoming SRP ( $C_e/C_0$ ) for the pilot cells and adjacent surface water wetland. The dashed line is where  $C_e/C_0 = 1$ ; data above this line represent an export of SRP. Sampling of the surface water wetland did not begin until day 60. Cell A (masonry sand) developed a leak early in the study and was taken off-line.**

We used the volume of wastewater treated (Table 2) and the mean delta P for each material (Table 3) to calculate the annual amount of P retained per unit area. By this calculation, masonry sand retained (mean ± standard deviation) 45 ± 62 g of P/m<sup>2</sup>/yr. Expanded shale retained over 3 times more P than masonry sand at 164 ± 110 g of P/m<sup>2</sup>/yr. Estimates of P retention for both materials are much higher than P

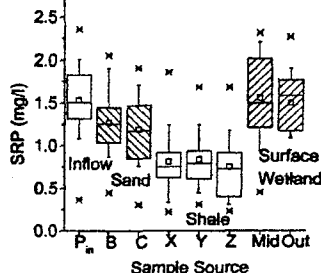


FIGURE 7. Box plots of incoming wastewater ( $P_{in}$ ), effluent from two sand pilot cells (B and C), three shale pilot cells (X, Y, and Z) and two locations within the surface flow wetland (Middle and Out). Sand pilot cell A was taken off-line due to a leak early in the study. Horizontal lines denote the 25th, 50th, and 75th percentile values. The error bars denote the 5th and 95th percentile values. The two symbols below the 5th percentile error bar denote the 0th and 1st percentile values. The two symbols above the 95th percentile error bar denote the 99th and 100th percentiles. The square symbol in the box denotes the mean of the column of data.

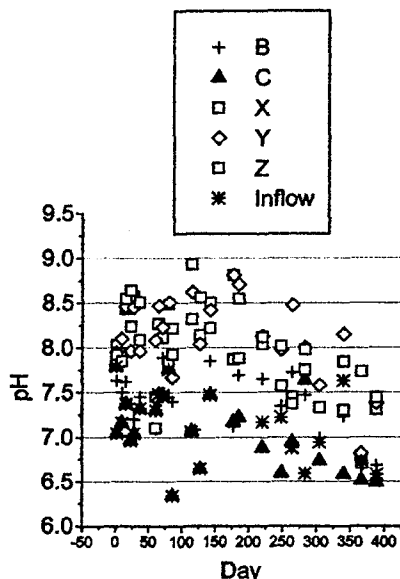


FIGURE 8. Pilot cell and inflow pH over the course of the study. Cells B and C contain masonry sand and Cells X, Y, and Z contain expanded shale.

retention via peat accretion in surface flow wetlands, which is generally regarded to be only 0.5 g of P/m<sup>2</sup>/yr (2). They are also substantially higher than P retention estimates for surface flow wetlands treating river water with high particulate P loads. For example, we calculated P retention of 4.4 g/m<sup>2</sup>/yr for a constructed flood plain wetland receiving Trinity River water (24). Mitsch et al. (25) reported 0.5–3.0 g/m<sup>2</sup>/yr P retention in constructed wetlands along the Des Plaines River. Incoming concentrations of suspended solids were high in both studies; thus, the primary mechanism of P removal was attributed to sedimentation.

In 24-h isotherm experiments, column flow-through studies, and longer-term pilot cell operations, our expanded shale demonstrated retention of dissolved P. Initial sorption, which usually occurred at high pH, is rapid, probably due to ion exchange (physical sorption) and ligand exchange (chemical sorption) with surface hydroxides. Slower, prolonged P retention by expanded shale may be associated with chemical and physical sorption to less accessible sites located within micropores of this porous material. Longer term sorption may also be a function of diffusion of P into

the interior of the particle. As pH decreased in column and pilot cell studies, reactions with hydrous oxides of Al + Fe would be favored, and formation of Al–P, as well as Fe–P compounds, may contribute to the long-term P retention in expanded shale columns and pilot cells. Releases of previously sorbed P from expanded shale were minimal in desorption experiments and were not observed during the field studies. Subsequent sequential fractionation of material taken from the pilot cells indicates that Fe + Al bound P (extracted with NaOH) was the most important storage compartment for retained P (26). Given the high Al + Fe content of the material, these results are consistent with our expectations that expanded shale would provide high sorption capacity that would not be easily reversed. Other researchers (27, 28) have found that sorption capacity of materials such as zeolite and light expanded clay aggregates (LECA) were closely correlated to both oxalate extractable Fe + Al.

Despite some reported successes with sand in subsurface flow treatment wetlands, our study found that masonry sand is a poor candidate for dissolved P retention. Its P sorption capacity as estimated by the Langmuir sorption model was only 58.8 mg/kg, compared to 971 mg/kg for the expanded shale. Masonry sand also readily desorbed P when exposed to more dilute solution in both isotherm desorption and column experiments. Some of the low P retention by masonry sand may have been due to its poor hydraulics. Although sand's hydraulic conductivity ( $K$ ) in the lab seemed adequate, when scaled up to the columns and pilot cells, flow rates were much lower and short-circuiting occurred. The aerial retention rate of expanded shale was 40 times greater than P retention reported for sedimentation and over 100 times greater than global estimates of peat accretion. We attribute this in part to the excellent hydraulics provided by expanded shale as well its high surface area and sorption affinity. By contrast, the adjacent, aged, surface flow wetland randomly exported P, probably due to P saturation of sediments at the sediment–water interface. Given the high rates of soluble P retained by expanded shale in our subsurface flow pilot cells, these systems warrant further and longer term study.

### Acknowledgments

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***“Introducing the Friendly material: Rotary Kiln  
Produced Lightweight Soil Conditioner”,***

**ESCSI Publication #8600 August 2002.**

# Introducing the *Friendly Material:* Rotary Kiln Produced Lightweight Soil Conditioner



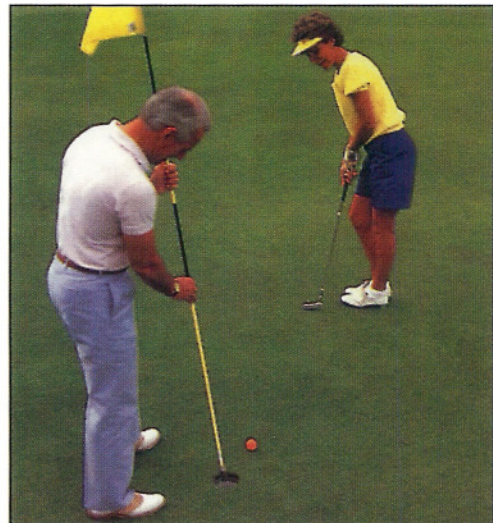
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*Elevated Plazas  
Lightweight Fill & Drainage Vehicle*

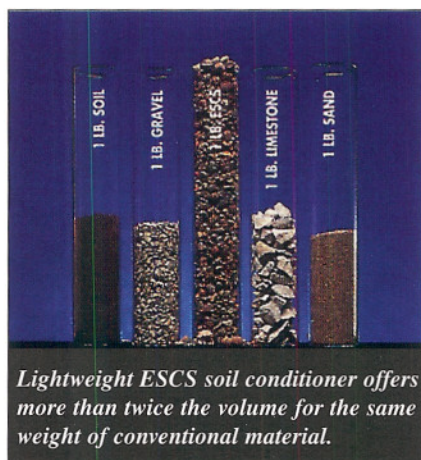


*Golf Greens & Lawns  
Soil Conditioner & Drainage Medium*



## Friendly to Our Environment: Gardens, Lawns, Shrubs, and Trees Grow Right and Look Great!

Lightweight Expanded Shale, Clay and Slate (ESCS) soil conditioner is playing a new and valuable role in today's horticulture. Produced by firing shale, clay, or slate in a rotary kiln at temperatures in excess of 2000°F, this fully calcined, ceramic material offers superior solutions of many of today's horticulture problems.



## Non-Toxic

Lightweight ESCS soil conditioner is clean, odorless, and contains no toxic minerals that could be damaging to plant or animal life.

## 100% Inert

ESCS is ceramic, 100% inert and completely inorganic. It can be blended with other soil supplements. It will not compress, decompose, or react with agricultural or horticultural chemicals. This fully calcined material is highly predictable, consistent, and stable over time under varying soil conditions.

## Strong and Durable

The material is strong and will not degrade during shipping, handling, or use in hydroponic or ground cover applications.

## Insulates

ESCS's low density acts as an insulator in the soil matrix protecting plants from rapid temperature extremes. When used as a mulch, ESCS insulates the plant root system from heat and freezing temperatures, thus helping the plant survive severe weather conditions.



*Lawn without ESCS... and with ESCS*

## Environmental Buffer

Lightweight ESCS soil conditioner provides an excellent environment for healthy root structure. ESCS retains as much as 12% to 35% of its weight in absorbed water and water-borne nutrients. Water and nutrients are steadily released as the soil dries. This creates a buffer to help protect plant life from high concentrations of chemicals and persistent drought. These characteristics also help prevent soil cracking and crusting.

## Aerates Soil

ESCS's porous micro-surface texture and interior porous structure resist clogging and provide superior aeration that promotes growth of delicate, fine root systems. Problems of soil compaction are significantly reduced when ESCS is properly proportioned within the soil. The soil remains resilient because moisture and air movement are not restricted. ESCS provides the optimum condition for fast, healthy plant growth.

## Friendly to Users: Lightweight ESCS Soil Conditioner is the Preferred Consumer Choice!

## Light in Weight

Lightweight ESCS soil conditioner weighs only one-third the weight of regular rock or sand – a definite advantage when transporting, handling, and installing the material! Yet it is heavy enough not to blow or wash away under normal weather conditions. The material does not float up or sink out of blended medium.

## Sterile

ESCS is sterile because it is produced at temperatures in excess of 2000°F. It is free of insects, disease, weed seeds, and soil-borne pests. It is ready to use without steam sterilization or chemical treatment.

## pH Factor

ESCS can be either slightly acidic or alkaline. It can be easily changed or "charged" with chemical supplements to any acidic or alkaline condition, depending on the pH requirements of the growing medium. It offers exact, dependable balancing of chemicals for rapid growth.

## Custom Mixtures and Blends

ESCS comes in a variety of sizes that can be blended for custom field conditions to achieve optimum pore structure and oxygen levels at the root zone.

## Low Maintenance

Areas properly landscaped with ESCS require no refurbishing. When used as a ground cover, ESCS should be placed over geotextile fabric to prevent the growth of grass and weeds.



# Multiple ESCS

## Applications:

- Gardens & Lawns
- Golf Courses & Ballfields
- Urban Trees
- Elevated Parks & Plazas
- Potting Medium
- Top Dressing & Mulch
- Roof Gardens
- Window Boxes
- Hydroponic Medium

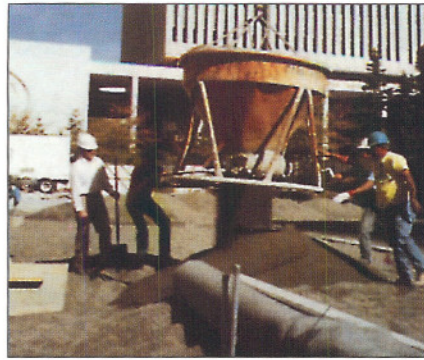
## Decorative Ground Cover and Mulching Material

This colorful, decorative ground cover comes in a variety of natural colors that provide the perfect background for landscaping shrubbery. Because of its neutral "all natural" color range, ESCS blends with its surroundings. Whether for walkways, garden enhancements, or ground cover, it hides unsightly or hard-to-maintain soil. ESCS soil conditioner works well as the mulching material around trees and shrubs. It helps prevent rapid evaporation of soil moisture, especially in dry weather. Color modification is also available, depending on the supplier.



Trees in downtown Brooklyn, New York, are planted in a soil mixture 2' deep, containing 50% ESCS to sustain heavy pedestrian use.

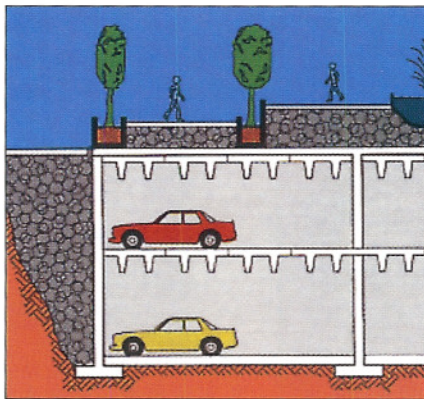
Lightweight ESCS fill and soil conditioner makes elevated parks and plazas possible.



During Construction

## Design Freedom

Architects and engineers have greater freedom in design when using Lightweight ESCS fill and soil conditioner. By reducing the dead load, it is possible to construct elevated parks, landscapes, and rooftop gardens without excessive structural cost. The tops of buried parking structures, water tanks, and marshland areas can readily be converted to lush, beautiful gardens and recreation areas. ESCS fill is also used to reduce pressure behind retaining walls, to insulate underground structures, and to provide a stable drainage medium.



Lightweight ESCS fill reduces dead load and structural cost.

## Potting Soil

An excellent potting soil can be produced by blending ESCS, organic components, and soil in approximately equal proportions. Potting plants use ESCS soil conditioners to help insure healthy growth. A generous layer in the bottom of solid-bottom pots will absorb excess water when plants are slightly over-watered. A layer of Lightweight ESCS in the bottom of



After Construction

pots with holes will hold the potting soil in place and still allow proper drainage and root development. Use ESCS to cover the top surface of the pot to give a neat, attractive appearance. ESCS will retain moisture and reduce the need for frequent watering while allowing good airflow.

## Hydroponic Medium

When used as a hydroponic medium, ESCS provides a reusable medium for water and nutrient passage. ESCS can be shaken free from roots, sterilized, and used repeatedly.



ESCS, as a hydroponic medium, is non-degrading and works well with drip systems, flood systems, and planter sub-base.

## Bottom-Line Cost Effective

ESCS is typically less expensive than competitive products in any given application. Additional savings may be realized with reduced water usage, better plant performance, reduced dead load, lower maintenance, and lower shipping costs. **Pound for pound, you get more for your money and pay less freight with lightweight ESCS soil conditioner.**



## Design and Material Considerations

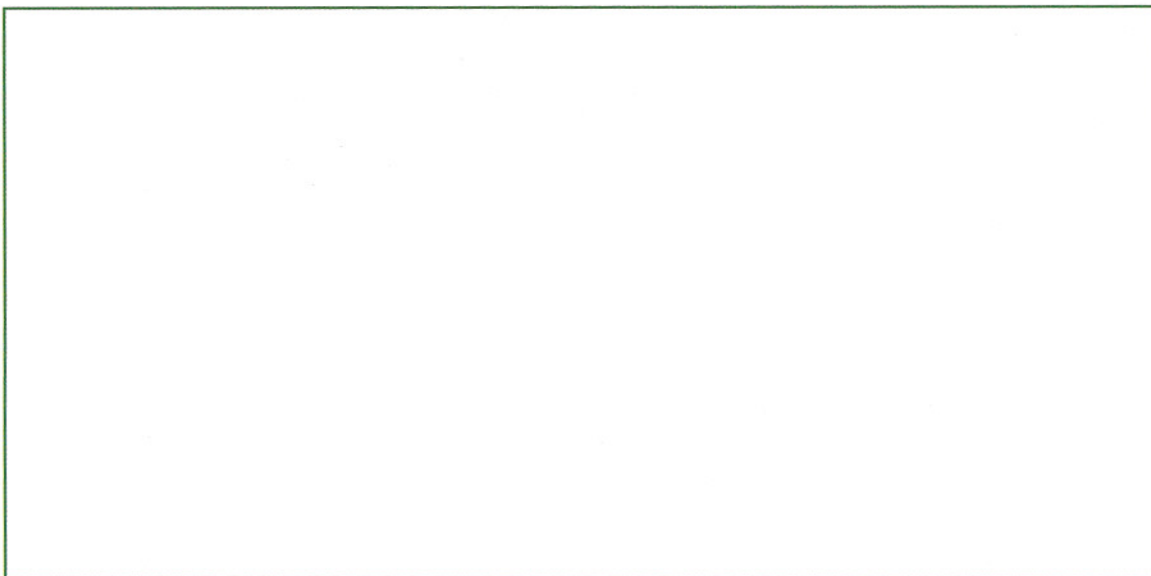
Originally patented in 1918 as Haydite, Expanded Shale, Clay and Slate Lightweight Soil Conditioner is the environmentally sensitive natural product of the future. Its technology has been tested as a growing medium in hydroponics, drainage, soil conditioning, cover material, and as a responsive carrier to conditioning chemicals.

The physical properties for lightweight ESCS soil conditioner may vary according to manufacturer. For precise information on mix design, unit weight, and other physical properties of a particular material, consult with a rotary kiln ESCS producer in your area.



*Lightweight ESCS soil conditioner and fill is produced in vary gradations, textures, and colors. It is readily available and can be shipped long distances because its density is less than half that of normal sand or gravel.*

For additional information about ESCS Soil Conditioner,  
contact ESCSI or your local producer/supplier.



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***ESCSI***

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**15F**

***“Amending Soils for Turf”***

**ESCSI Publication 8620**



# TURFMatrix™

A Superior Soil Amendment

## Amending Soils for Turf

Lawns

Golf Greens

Golf Fairways

Soccer Fields

Baseball Fields

Football Fields

Tennis Courts

Polo Grounds

City Parks

..... *Everywhere  
you grow!*



# *Rooted In Excellence*





## INTRODUCTION

With the advent of sports turf, golf greens, and professional lawn care, the science of turf grass management has taken a giant step forward. All healthy turf has one thing in common: *a good root system*. Roots that can move through the soil freely help grass plants establish and recover more quickly than those that are placed in compacted and poorly drained soils. Compacted soils force roots to grow very near the soil surface. This greatly reduces drought resistance and increases the possibility of diseases from poor drainage. It is generally understood that to achieve healthy turf, it may be necessary to amend soils with materials that promote strong root development. Properly amended soils will yield strong, healthy turf that requires less maintenance. It not only protects your investment, it enhances it.

## A GOOD SOIL PROFILE

Soil is a fragile growing medium consisting of three components: solid particles, water and air. It is necessary to maintain a careful balance of these elements to establish a good soil profile. Generally speaking, a good soil profile is approximately 25% water, 25% air, and 50% solid particulate matter. However, when soils are compacted the profile becomes unbalanced as a result of changes in the soil structure. Solid particles are pressed together eliminating space for the water and air. With less pore space, soils become too dense for the movement of water and for the exchange of air and nutrients. With this compacted soil condition, the favorable environment for the beneficial microbial activity necessary for a healthy growing medium is lost.

## SOIL AMENDMENTS

Soils are not generic in structure, so why should the methods of conditioning them be? By providing adequate drainage, reducing nutrient loss,



Deep drought-resistant roots on putting green

improving moisture retention, enhancing soil resiliency, and increasing resistance to compaction, a balanced soil can be achieved. Organic amendments are essential for healthy balanced soils, but they absorb water and without adequate air and drainage can contribute to the growth of harmful fungi and bacteria. Historically gardeners added grit or sand to the soil to help aerate it. However, over time the soil becomes compacted around these solid particles, the pore space is reduced, and the air supply to the roots is cut off. Some sands can also leach minerals into the soil and affect nutrient balance. Products such as vermiculite, perlite, foam beads, and partially calcined clays are marketed to aerate soil. As part of the soil mix, all these additives tend to break down over time, crush, or get carried away by wind or water. Only **TURFMatrix™** can provide an essentially permanent, single application solution.



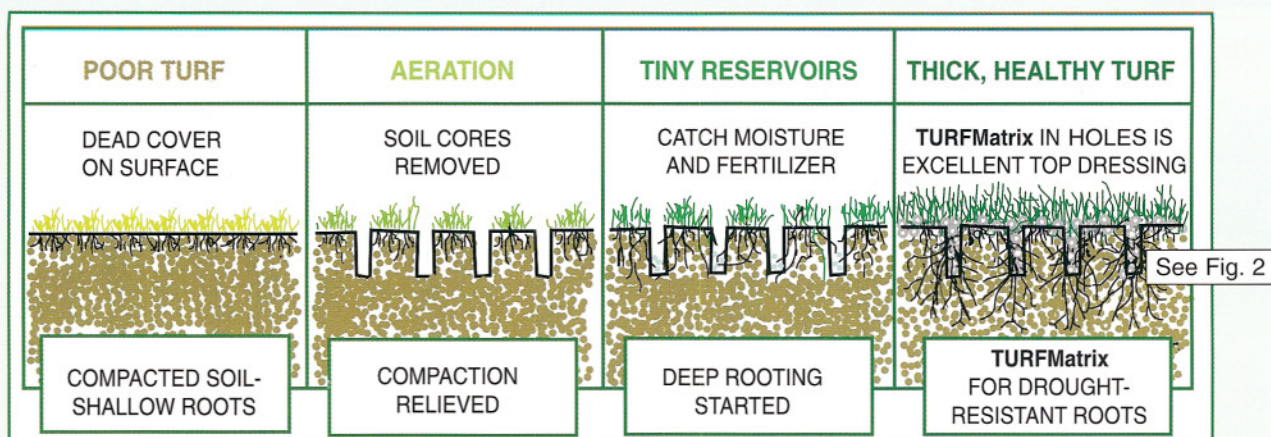


Fig. 1 - Mechanical Aeration.

### Topdressing Existing Turf \* (Fig. 1)

Topdressing with **TURFMatrix** on existing turf can be applied under two conditions. First, and best, is following mechanical aerification. The **TURFMatrix** is applied to closely cropped and aerated turf surface to form a 3/8" to 1/2" uniform layer. The applied material can then be raked into the 2" to 4" deep core holes, or simply allowed to drop into the holes without raking. Either way, **TURFMatrix** ultimately becomes a permanent addition to the soil profile.

Another way to apply **TURFMatrix** topdressing is to spread it evenly in a 3/8" to 1/2" layer on closely cropped, non-aerated turf. Though not as effective as when combined with mechanical aeration, the **TURFMatrix** will eventually work into the thatch layer and improve drainage, fill low spots, and help provide a more level surface. Additionally, it helps promote the microbial action which breaks down thatch and organic matter to improve nutrient availability to the grass plants.

### New Lawn Construction\*

**Heavy Clay Soils?** Soils that consist of tiny plate-like natural clay particles compact easily and lack pore spaces for air, water and humus. Natural clay particles hold moisture and further reduce the amount of available air pore space. Breaking up clay soil to depths of 8" to 12" is the first and most physically demanding step.

**Soil Preparation:** **TURFMatrix** is best incorporated into the soil before seeding or placement of sod. Apply the recommended rate of fertilizer, along with any required soil amendments such as lime or gypsum, to the surface and till or disk the soil as deep as possible before applying **TURFMatrix**. Next, spread **TURFMatrix** evenly on the surface to a depth of 1" to 2". The addition of a 1/2" to 1" layer of organic matter, preferably a good compost, at this time is also recommended. After **TURFMatrix** and compost have been spread, till or work it into the soil to a depth of 6" to 8". Then, rake the soil smooth. The soil is now prepared for seed or sod placement before the next rain or watering cycle. *\*Topdressing and new lawn construction material is normally a minus 1/4"-graded material. However, you should contact your local supplier for specific grading information.*

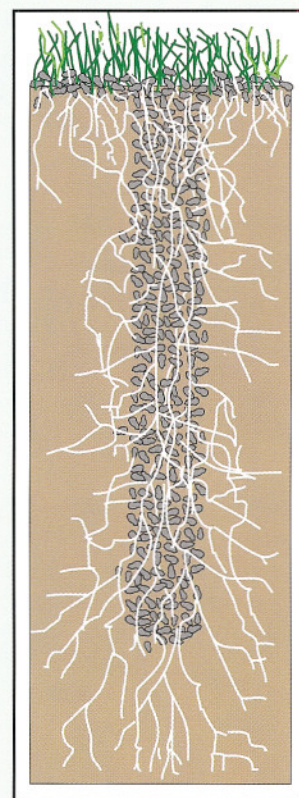


Fig. 2 - Mechanical Aeration with **TURFMatrix** top dressing



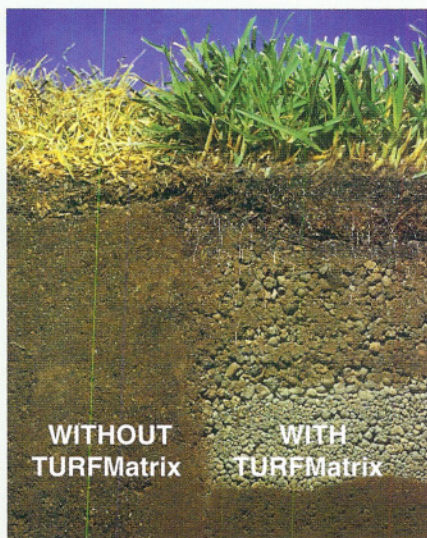


Fig. 3 - Soil with and without TURFMatrix structural soil

## STRUCTURAL SOIL CONSTRUCTION

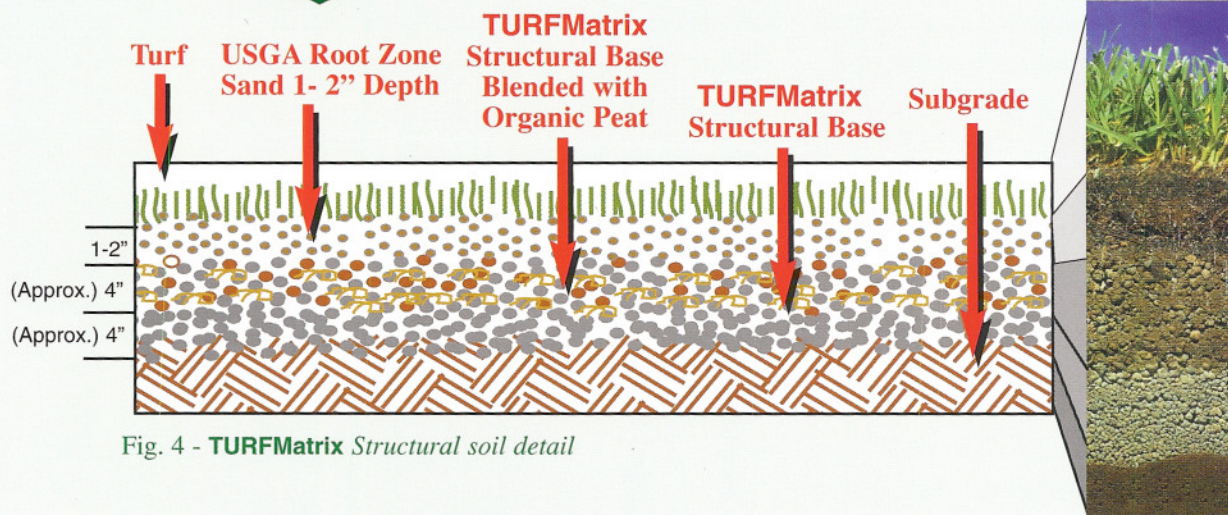


Fig. 4 - TURFMatrix Structural soil detail

## Structural Soil Construction (Fig. 3 and Fig 4)

After the subgrade is uniformly compacted to 95% of its maximum dry density, the 3/8" to 1/4"-size **TURFMatrix** can be placed in uniform lifts over the entire area, and compacted (using a vibratory plate compactor) to provide a finished depth of about 8". A blend of TurfMatrix and organic peat is often used to create the upper half of this compacted layer as shown in Figure 4. A 1" to 2" layer of USGA root zone mix is then placed on top of the compacted **TURFMatrix**. It is now ready for seed or a sand-based sod. If the subgrade is impervious to water, a drainage system may be required. Once the turf is established, the system will support a quality lawn, and, in the event of an emergency, a fire truck, crane or other heavy equipment.



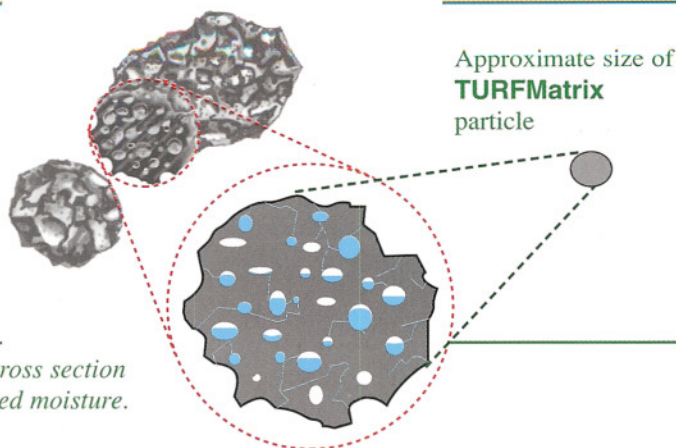


Fig. 5 - Enlarged **TURFMatrix** particle and cross section showing internal cellular structure with retained moisture.

### WHAT IS **TURFMatrix**™?

**TURFMatrix** is a ceramic material produced by expanding and vitrifying specially selected natural shale, clay, or slate material in a rotary kiln at temperatures in excess of 2000° F. This process makes **TURFMatrix** agriculturally sterile and environmentally inert. It is not a chemical.

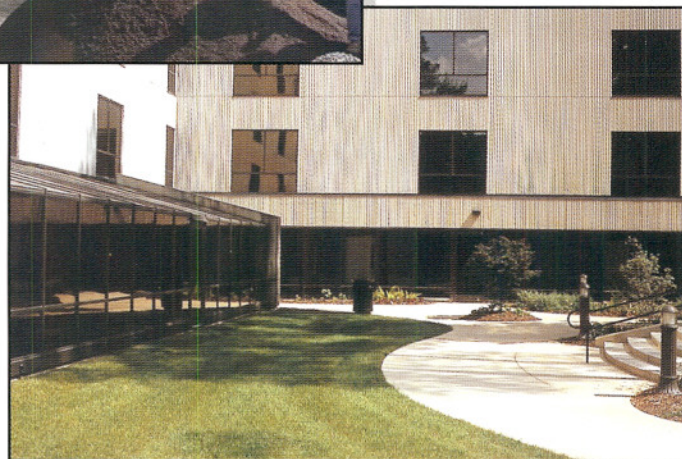
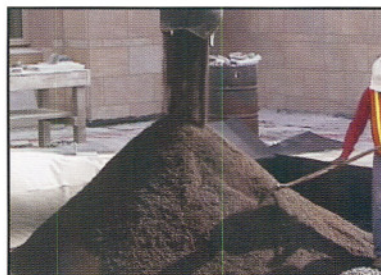
**TURFMatrix** is a non-toxic, generally neutral pH, absorptive granule made from natural material (Fig. 5). It is dimensionally stable and will not degrade or compress like other soil conditioning products. **TURFMatrix** does not need to be re-applied year after year.

### HOW **TURFMatrix**™ WORKS

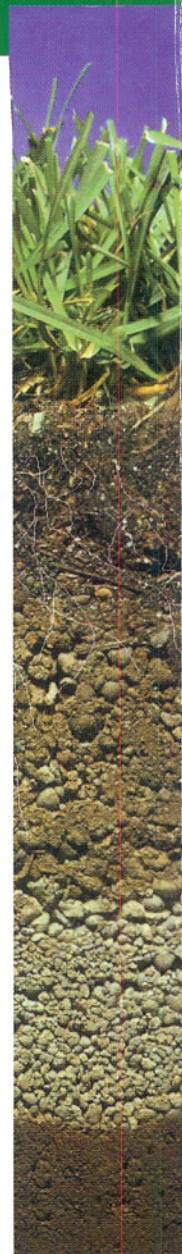
The porous, cellular nature of **TURFMatrix** helps manage water and fertilizer use, reduce compaction, increase soil porosity and maintains soil temperature. Because it has cation-exchange-capacity, **TURFMatrix** reduces nutrient loss through leaching. It retains moisture during dry periods and slowly releases it along with any soluble nutrients for the plant roots. **TURFMatrix** also helps drain and aerate wet soils and provides an environment suitable for beneficial microbial action. This makes it an excellent addition to compostable materials and enhances the composting process.

### GIVE YOUR TURF A HEAD START

So how are healthy soils achieved? The use of **TURFMatrix**, or any other soil amendment, alone does not guarantee the success of a turf or lawn system. Soil make-up, climate, application technique, grass type and follow-up maintenance are also factors. However, the process of optimizing the potential of your soil is begun by amending it with **TURFMatrix**. It gives your soil and turf a head start, and a much greater chance for a spectacular finish with a stronger, thicker, healthier stand of grass.



*Courtyard at Duke University Medical Center*







# TURFMatrix™

## A Superior Soil Amendment

**For additional reference, see the following publications:**

- **ASTM D 5268 - 92 (Reapproved 1997):** *Standard Specification for Topsoil Used for Landscaping Purposes*
- **ASTM D 5883 - 96:** *Standard Guide for Use of Rotary Kiln Produced Expanded Shale, Clay or Slate (ESCS) as a Mineral Amendment in Topsoil Used for Landscaping Purposes*
- **ESCSI Publication No. 7600:** *Expanded Shale, Clay and Slate – A World of Applications . . . Worldwide*
- **ESCSI Publication No. 8600:** *Introducing the Friendly Material: Rotary Kiln Produced Lightweight Soil Conditioner*
- **ESCSI Publication No. 6600:** *Rotary Kiln Produced Lightweight Aggregate for Geotechnical Applications*

### ***Rooted in Excellence Everywhere You Grow!***

***Choose from 3 Growth-Promoting Products.***



**SOILMatrix:** *For amending soils in containers and planting beds for flowers, shrubs or other landscaping plants (Not covered in this brochure)*



**TURFMatrix:** *For amending soils to promote thick, healthy, drought resistant turf and reduce maintenance requirements*



**TREEMatrix:** *For amending soils to promote healthy tree growth and reduce potential for root damage to pavement or other surface structures (Not covered in this brochure)*

**For additional information, contact your local supplier.**



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**15G**  
***“GreenRoofs”***

**ESCSI Publication #8621**



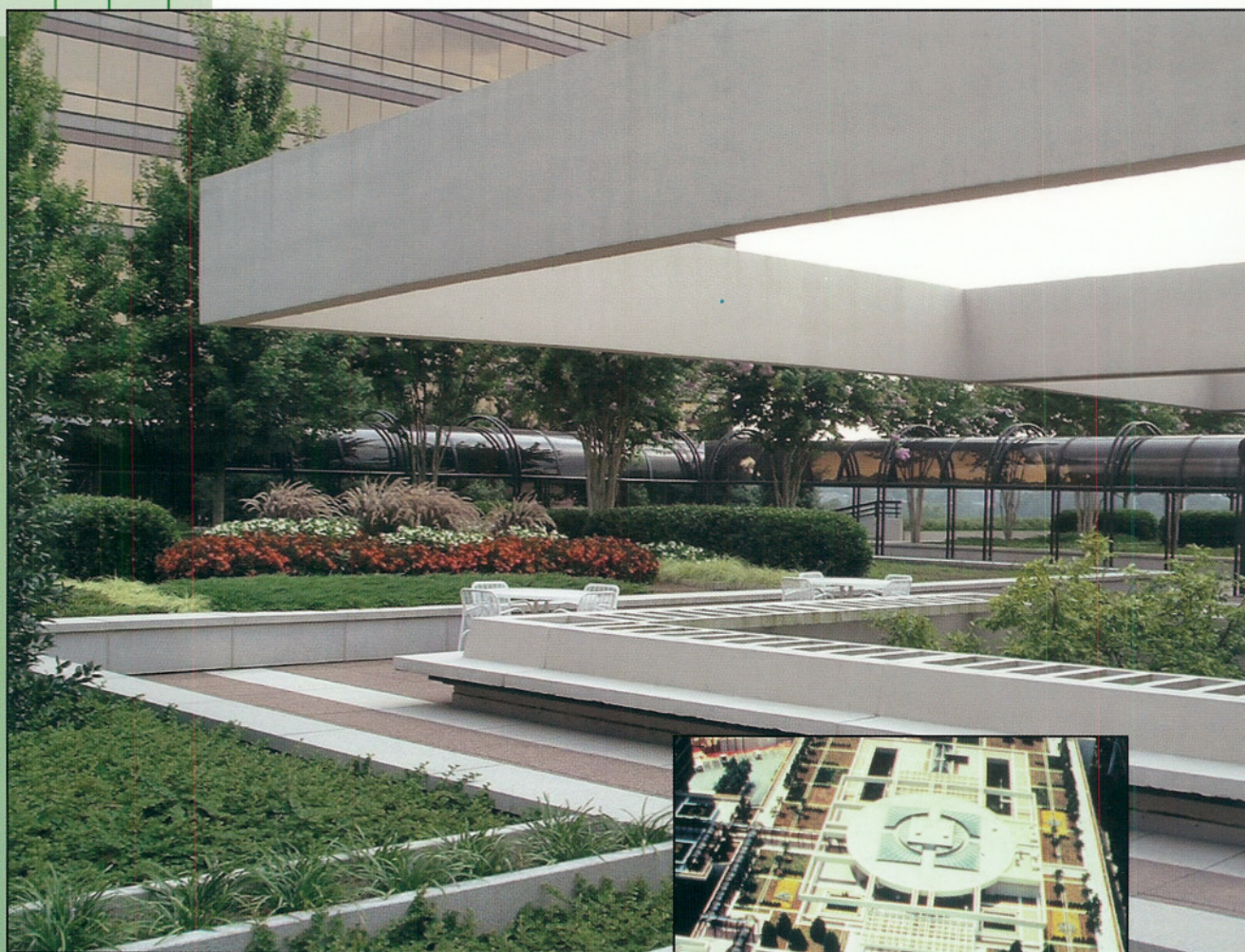


# GREENROOF

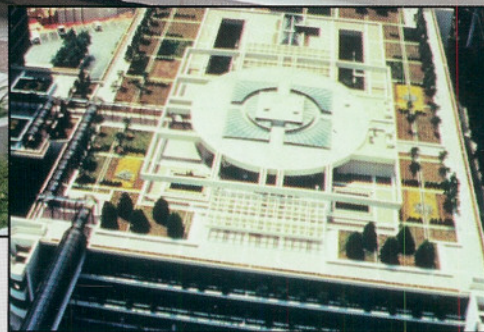
## SOILMatrix™

### GIVES YOUR GREENROOF

### THE LIGHTWEIGHT ADVANTAGE



(Above) Intensive Roof Garden  
North Park 400, Atlanta GA  
Installed 1997; Pictured 2002



(Inset) Aerial view of North Park  
roof after installation in 1997



# SOILMatrix™

## GIVES YOUR GREENROOF

## THE LIGHTWEIGHT ADVANTAGE

SOILMatrix has a long history of success in horticultural applications all over the world. It is marketed under various trade names and has established itself as the standard for creating planting media for rooftop gardens. This track record of proven performance demonstrates how SOILMatrix, at about 50% of the weight of natural planting media, contributes to sustainable development by conserving energy, reducing trucking requirements and minimizing the impact on structures. The use of this environmentally friendly ceramic material in green-roof design helps address important issues such as managing storm water runoff, improving water quality, reducing urban heat, conserving energy, lowering dead load and increasing green space.



SOILMatrix being installed at LDS Conference Center

### Greenroof Planting Media

One of the most important components to both extensive and intensive greenroof systems is a quality planting medium. Because of the complex nature of greenroof construction and the difficulties of access after completion, the planting media must be able to support and sustain plants for the duration of the intended life span of the roof. A well-designed planting medium will have the following physical characteristics:

- **Be free of silts and clays that could clog the filter fabric;**
- **Have permanent internal aeration even after several years of consolidation;**
- **Insure adequate drainage;**
- **Insure stable root support;**
- **Not degrade, breakdown or shrink in volume over time.**

SOILMatrix is the environmentally friendly answer that provides a long-term solution to the above complex design requirements.

Besides exceeding all the requirements of an ideal planting medium, SOILMatrix provides additional important benefits. Its reduced weight can often accommodate structural design requirements; yet it is heavy enough to avoid loss caused by excessive wind or water. Its angular, stable and



SOILMatrix planting medium promotes healthy root development.



7-acre rooftop garden atop LDS Conference Center in Salt Lake City, UT.



Perimeter planting on roof of LDS Conference Center in Salt Lake City, UT.



Extensive greenroof garden, City Hall, Atlanta, GA, 2004



SOILMatrix installed by blowing equipment atop six-story Atlanta City Hall



porous ceramic nature ensures an adequate supply of air to enable **plants to be established quickly and develop healthy root systems.**

Ample aeration increases the insulative properties of the planting media and helps reduce energy consumption as well as lessen the urban heat island effect. Overall project costs are often reduced because SOILMatrix can also serve as the drainage portion of the greenroof system. When used for storm water management, the porous planting medium allows rain water to readily penetrate the soil surface. This reduces runoff and allows pollutants to be naturally filtered and remediated thereby improving water quality.



Connecticut Convention Center, Hartford, CT. 9th floor walkway from the convention center to the parking garage.



SOILMatrix particle showing interior voids

## What is SOILMatrix?

SoilMatrix is a lightweight, ceramic material produced by expanding and vitrifying select shales, clays and slates in a rotary kiln. The process produces a high quality ceramic aggregate that is structurally strong, physically stable, durable, environmentally inert, light in weight, and highly insulative. It is a non-toxic, absorptive aggregate that is dimensionally stable and will not degrade over time.

## SOILMatrix: A comparison to other aggregates

Natural sand and soil are heavy. They frequently require that structural modifications be made to the project's design. Native soils have silts and clays that may clog the filter materials or drainage layers and reduce effectiveness. The physical properties of natural volcanic aggregates vary widely with source and location. Natural materials may degrade and compact over time, and require additions to or replacement of planting media. Some horticultural products used in greenhouses and container planting, such as vermiculite and perlite, are extremely light in weight and do not offer adequate anchorage and support for larger plants. In exterior applications vermiculite and perlite often float to the top of the planting media where they can be carried away by wind or water.



Tubes containing equal weights of soil, gravel, SOILMatrix, limestone and sand to demonstrate the difference in relative volume.

## LEED™ Benefits

The Leadership in Energy and Environmental Design (LEED) system was designed by the United States Green Building Council (USGBC) to evaluate the influence of building design and construction on the environment. SoilMatrix is an environmentally friendly, lightweight, ceramic product that saves material, labor and transportation cost. It also improves the functionality and service life when used in greenroofs and other planting media. These benefits support sustainable development and contribute to designs becoming LEED certified. For more detailed information on LEED, see ESCSI Publication # 7700.

### LEED-NC Rating System Summary (Version 2.1)

Category	Available Points	Points Where SOILMatrix Can Contribute
Sustainable Sites (Section 6.1, 6.2, 7.1, 7.2)	14	4
Water Efficiency (Section 1.1, 1.2, 2)	5	3
Energy & Atmosphere	17	(see note 1)
Materials & Resources (Section 5.1, 5.2)	13	2
Indoor Environmental Quality	15	(see note 2)
Innovation & Design	5	(see note 2)
<b>Total Possible Points</b>	<b>69</b>	<b>9+</b>

**Note (1):** 1-10 points can be awarded for energy cost savings of 15%-60% for new buildings and 5%-50% for existing buildings. Improving the thermal performance of building materials contributes toward obtaining these credits. **Note (2):** Ideal for indoor planting media.



## SOILMatrix: The Versatile Planting Medium

Designers can count on SOILMatrix to be predictable, stable and highly dependable for the duration of the greenroof. The planting media mixture will vary depending on the climate region, application, aggregate and types of plantings specified. For optimal results it is essential to consult with the SOILMatrix supplier during the design phase of the project.



Sedums flourishing in extensive SOILMatrix blend



2 views of greenroof at LDS Conference Center, Salt Lake City, UT

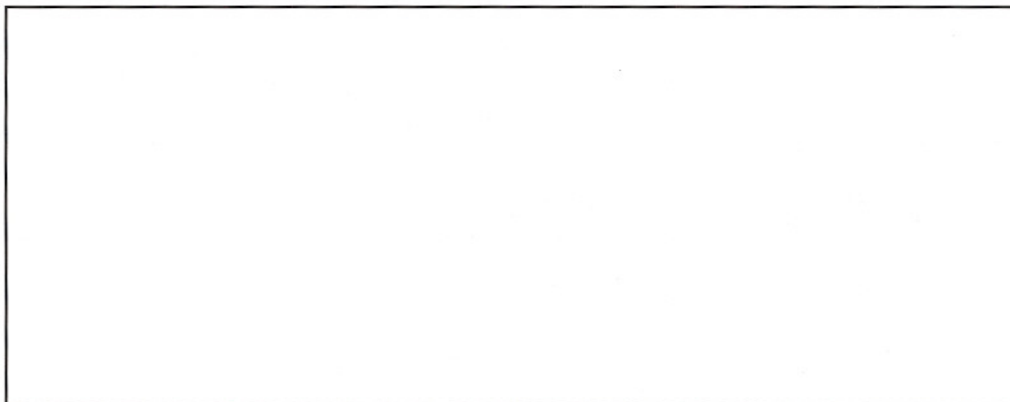


**SOILMatrix™**

**GIVES YOUR GREENROOF  
THE LIGHTWEIGHT ADVANTAGE**

SOILMatrix is readily available throughout the United States and Canada,  
and is sold under various trade names.

For additional information and technical support contact the local supplier or



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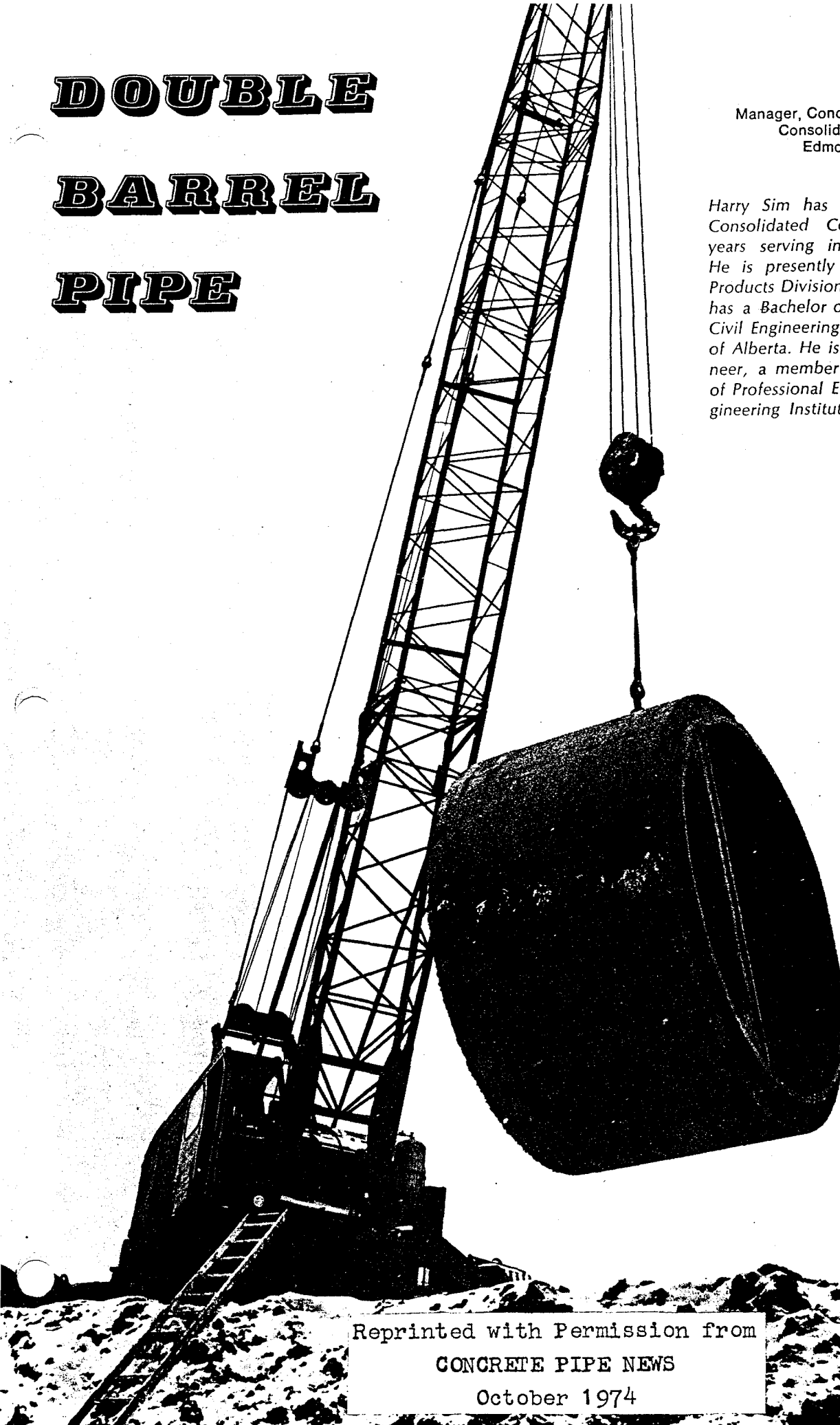
**Concrete Pipe News October 1974**

**“Double Barrel Pipe”**

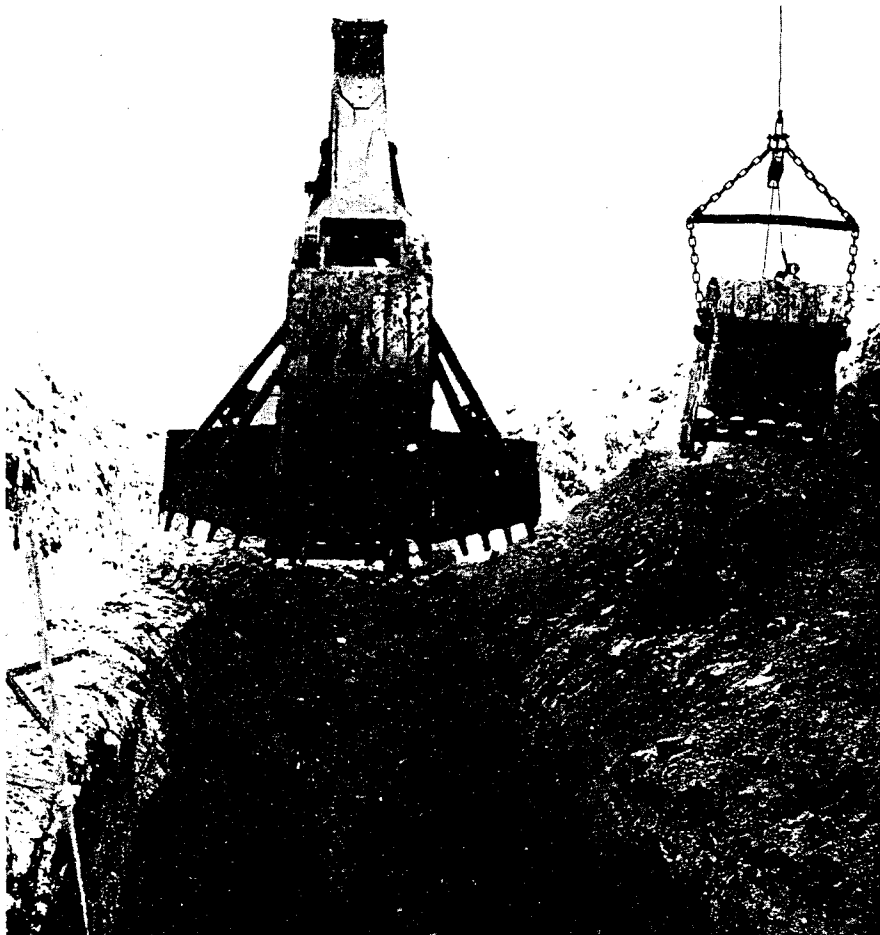
# DOUBLE BARREL PIPE

by  
Harry E. Sim, P.Eng.  
Manager, Concrete Products Division  
Consolidated Concrete Limited  
Edmonton, Alberta, Canada

*Harry Sim has been employed by Consolidated Concrete for eleven years serving in various capacities. He is presently Manager, Concrete Products Division in Edmonton. Harry has a Bachelor of Science degree in Civil Engineering from the University of Alberta. He is a Professional Engineer, a member of the Association of Professional Engineers and the Engineering Institute of Canada.*



Reprinted with Permission from  
CONCRETE PIPE NEWS  
October 1974



*Backhoe bucket was enlarged 39 inches on each side by the addition of wings with teeth.*

*Trench was widened at top of pipe to provide work area and location for batter boards.*



**D**evelopment of the southeast Mill Woods area of the City of Edmonton called for the construction of a new interceptor sewer. Mill Woods is a land bank area located in the southeast section of Edmonton on virgin territory but within the city limits. It is being developed by the City of Edmonton to stabilize the cost of housing in the Edmonton area.

Frank Berezky, Chief Drainage Engineer, Edmonton Water and Sanitation opted to utilize a double barrel pipe concept that he had successfully developed and used previously. The concept was conceived to economically accommodate the separation of the present combined sewer system when the tunnel method of pipeline installation was used. The installations in downtown Edmonton were deep and were tunneled with a mechanical mole, Berezky's double barrel concept provides two sewer systems but requires only one bore. In this case, he felt the double barrel pipe would provide an economical installation even though the open cut method was employed.

This double barrel pipe concept uses a separating cross wall angled at 20° from the vertical to create two chambers within the pipe. The prescribed 20° angle takes advantage of the best flow characteristics. The cross wall was situated to provide the structural pipe with a storm chamber equivalent to a 99-inch diameter pipe and a sanitary chamber equivalent to a 38½-inch diameter pipe.

T. Lamb McManus and Associates, Limited were the engineers responsible for the structural design of pipe. The pipe was designed to meet ASTM Standards C76, Class IV for the ultimate 3-edge bearing test loading.

Consolidated Concrete Limited, Edmonton, at Berezky's request produced the 10-inch wall pipe using semi-lightweight concrete. The reinforcement was two cages

of wire mesh with mats where additional steel area was required. The additional reinforcement is not positioned as quadrant reinforcing because of the unusual stress distributions created by the cross wall. The cross wall was reinforced with two mats welded to the inner cage. Lightweight aggregate produced by Consolidated's Edcon Division was used in the production of the 6-foot sections of pipe.

Advantages of semi-lightweight pipe over normal weight pipe were numerous. Weighing 3,625 pounds per foot as compared with 4,725 pounds per foot for normal pipe, the lighter pipe made it possible to use smaller cranes on the jobsite, to utilize existing in-plant manufacturing equipment and to haul two sections of pipe per truck rather than one.

Development of the equipment for manufacture and actual manufacturing of the pipe was under the direction of Consolidated's production team of Herman Bruning, Len Stainbrook and Leo Theroux. The production used a normal outside form but the inside forms were modified. They were in effect two inner forms providing the two chambers required. The forms were stripped immediately after the production process was completed by overhead cranes and the pipe moved by lift truck to the kiln. Twenty pipe were produced per 9 hour shift and special manhole and bend sections were supplied as required. Jobsite coordination was provided by pipe sales representative George Richards.

The \$1,340,000 project for the installation of 3,200 feet of 111-inch double barrel pipe in addition to 2,600 feet of 96-inch vertical elliptical storm pipe laid in a common trench with a 27-inch sanitary pipe was awarded to Arthur A. Voice Construction.

Doug Ells, Voice's General Manager and Ed Oswald, job superin-

tendent, demonstrated their long years of experience in sewer construction by utilizing a 80-foot drag boom and a four yard drag bucket for the initial excavation of 65,000 cubic yards to a depth of 20 to 25 feet in a cut 52 feet wide. The machine was then converted to a backhoe. Voice extended the width of the 3½ yard backhoe bucket by the installation of 39-inch wings with teeth on each side. This made it possible to cut the final ditch for the installation of the 111-inch pipe to a width of 12 feet 6 inches and a depth of 16 feet in one pass.

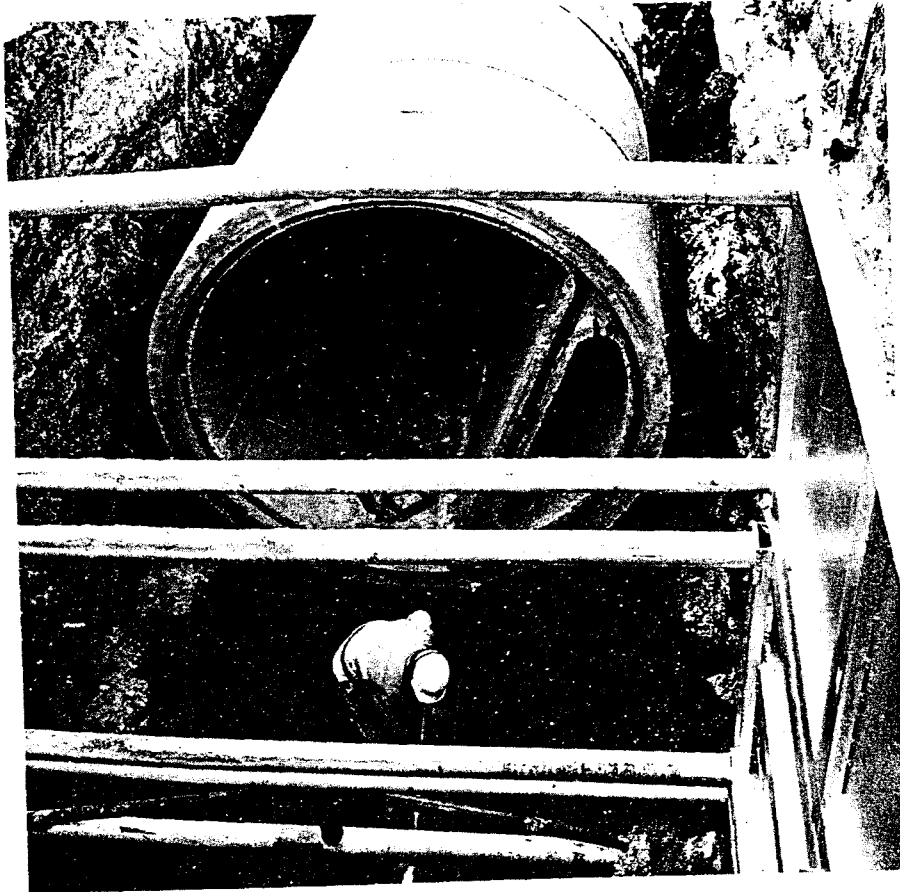
The material excavated by the backhoe was cast aside by a dragline located above the cut assisted by a front end loader.

The pipe was installed in a Class A concrete bedding by laying the pipe on a low slump concrete base and then using conventional slump concrete up to the spring line of the pipe. The orientation of the pipe in the trench was critical because of the alignment required for the cross wall. During production of the pipe Consolidated carefully located the lift holes in the crown of the pipe at the proper balance point so that the cross wall would hang at 20° from the vertical. This accomplished an approximate orientation, the final orientation was done using a carpenter's level with a 20° triangular block attached. Compaction of backfill material to the finished grade surface com-



*Bedding material being placed in trench using concrete bucket. Note dragline in background moving excavated material away from trench.*





*Bedding being prepared prior to lowering of next section of pipe into trench.*

pleted this unique interceptor project.

This project is indicative of what can be accomplished with the cooperation of experienced designers, manufacturers and contractors.



*Section of pipe being guided into trench.*



# **15I**

**Summary of Preliminary Experiments  
Performed to Examine “FLAIR: Fine  
Lightweight Aggregates as Internal  
Reservoirs for the Delivery of Chemical  
Admixtures,” Bentz D.**





## : FINE LIGHTWEIGHT AGGREGATES AS INTERNAL RESERVOIRS



### **FLAIR-DCA – Fine Lightweight Aggregates as Internal Reservoirs for the Delivery of Chemical Admixtures**

Dale P. Bentz (BFRL/NIST)

FLAIR-DCA consists of a unique method to control the distribution/delivery of chemical admixtures within a hardening concrete. Recently, the usage of saturated fine lightweight aggregates to provide internal curing water to promote cement hydration in hardening concrete with a low water to cementitious binder ratio ( $w/c \leq 0.42$ ) has been demonstrated in the laboratory and the field. The novel aspect of FLAIR-DCA is to utilize these same internal reservoirs to supply chemical admixtures such as shrinkage-reducing admixtures, corrosion inhibitors, etc. to the concrete. As the cementitious components of the concrete react with the mix water, the hydration products occupy less volume than the starting materials. Thus, a concrete will imbibe water from its immediate surroundings or from internal sources to maintain a saturated capillary porosity. While to date, the internal reservoirs have been saturated only with water, they could equally be saturated with solutions of chemical admixtures.

Admixture delivery via these internal reservoirs can potentially offer several advantages over conventional delivery by direct addition to the mixing water. Some chemical admixtures such as shrinkage-reducing admixtures are partially absorbed by the cement hydration products. In this case, releasing the majority of the chemical admixture after some of the cement has already hydrated should result in a more efficient usage of the chemical. This would be the case should FLAIR be used to deliver the chemical admixture. Secondly, admixture combinations sometimes exhibit detrimental interactions. An example would be a shrinkage-reducing admixture which decreases the effectiveness of an air entraining admixture. By introducing the admixture that influences fresh concrete properties (air entrainment, rheology, setting) via conventional means and the admixture that influences hardened concrete properties (corrosion inhibition, shrinkage reduction, ASR mitigation) via the internal reservoirs, these detrimental interactions should be minimized.



## Summary of Preliminary Experiments Performed to Examine “FLAIR: Fine Lightweight Aggregates as Internal Reservoirs for the Delivery of Chemical Admixtures”

During the summer of 2004, preliminary experiments have been conducted to demonstrate the viability of using saturated lightweight aggregates (LWA) as chemical admixture delivery vehicles in mortar and concrete. Specifically, experiments were conducted to examine the efficiency of utilizing the LWA particles to deliver a shrinkage-reducing admixture to a hydrating mortar. Previously, it has been conclusively demonstrated that the separate additions of either a shrinkage-reducing admixture or saturated LWA to a mortar result in substantial reductions in autogenous shrinkage [1]. Thus, for a preliminary evaluation of the FLAIR technology, three different mortar mixtures were prepared:

- 1) a conventional mortar (mixture proportions are given in Table 1) with a low water-to-cement ratio (w/c) and no addition of either the chemical admixture or lightweight aggregates,
- 2) a mortar with the same cement paste w/c, but with the addition of a fraction of saturated lightweight aggregates (1.18 to 2.36 mm in diameter) and the addition of a shrinkage-reducing admixture to the mortar mixing water (mixture proportions in Table 2), and
- 3) a mortar with the same overall composition as mortar #2, but with the shrinkage-reducing admixture contained in the solution used to saturate the lightweight aggregates.

Table 1. Mixture proportions for control mortar #1

Ingredient	Mass (g)
CCRL Cement 152	1250.00
Water	365.40
Daracem 19 water reducer	16.00
F95 Sand	593.75
Graded Sand	451.25
20-30 Sand	451.25
S15 Sand	878.75

Table 2. Mixture proportions for mortars #2 and #3 with LWA and shrinkage-reducing admixture

Ingredient	Mass (g)
CCRL Cement 152	1250.00
Water	359.01
Daracem 19 water reducer	16.00
Eclipse shrinkage reducing admixture	6.39
F95 sand	593.75
Graded sand	451.25
20-30 sand	451.25
S15 sand	279.65
SSD LWA	383.33

The mortars were prepared in a Hobart blender following the standard practice and the following properties were evaluated (up to ages of about 28 days):

- 1) air content of the fresh mixture,
- 2) degree of cement hydration vs. time,
- 3) compressive strength development,
- 4) autogenous shrinkage, and
- 5) drying shrinkage.

A comparison of these properties will demonstrate the viability of utilizing the FLAIR system for the delivery of chemical admixtures in mortars and concretes.

#### 1) Air content of fresh mortar mixtures:

The following air contents were measured for the three mixtures: 1- 3.4 %, 2- 5.1 %, and 3- 8.3 %. Mixture 1 exhibits the lowest air content due to the overall low water content (dryness) of the mixture and the absence of any LWA particles. The specific shrinkage-reducing admixture employed in mixtures 2 and 3 is known to have air detrainment properties, so the increased air content of mixture 3 relative to mixture 2 indicates that following mixing, the shrinkage-reducing admixture was most likely still isolated within the porous LWA particles and had not yet distributed into the bulk mixing water. *This indicates that air detrainment problems experienced with the conventional addition of shrinkage-reducing admixtures could perhaps be avoided or lessened via the addition of the admixture using the FLAIR technology.*

#### 2) Degree of cement hydration and compressive strength development

The results for these two tests are both provided in Figure 1. Mixtures 2 and 3 are seen to have enhanced hydration relative to mixture 1 due to the extra internal curing water available within the LWA particles present in these mixtures. The compressive strength results basically indicate that equivalent strengths were achieved in the three systems. The strength enhancement expected to be found with the increased hydration in mixtures 2 and 3 was basically offset by the higher air contents of these mixtures. *These results demonstrate that the FLAIR delivery of the shrinkage-reducing admixture is equivalent to delivery by conventional means in terms of hydration and strength development.*

#### 4) Autogenous shrinkage

Autogenous shrinkage of the three mortars was measured using sealed plastic corrugated tubes. The lengths of the sealed specimens following setting of the mortar were measured using a digital dilatometer. Results are provided in Figure 2. While mixtures 2 and 3 both exhibit much less autogenous shrinkage than mixture 1 (due to the availability of the internal curing water), no significant difference between these two mixtures is observed. *This indicates that FLAIR delivery of the shrinkage-reducing admixture and water provides an equivalent reduction in autogenous shrinkage as delivery of the shrinkage-reducing admixture by conventional means.*

#### 5) Drying shrinkage

Drying shrinkage was assessed on prism specimens that were demolded after 1 day of sealed curing, maintained in sealed curing in double plastic bags until 3 days, and then exposed to a 23 °C, 50 % RH environment. Both the mass and length of the prisms were measured periodically. Drying shrinkage is largely controlled by the water loss from the specimens, as illustrated by the observed linear relationship between shrinkage and mass loss exhibited by all three mortar mixtures in Figure 3. Because the shrinkage-reducing admixture reduces the surface tension of the pore water in the mortar, it reduces the slope of the shrinkage vs. mass loss curves. This is clearly indicated for mixtures 2 and 3 in Figure 3. The data in Figure 3 was analyzed by linear regression to determine the slopes of the shrinkage vs. mass loss curves for two time regimes: 3 days to 7 days, and 7 days and beyond. At longer times, the shrinkage-reducing admixture released by the FLAIR system may be more efficient in reducing the drying shrinkage than that added by conventional means, which is perhaps absorbed by the cement hydration products. These results are summarized in Table 3. In every case, an excellent linear fit to the data was obtained, as indicated by the values of the correlation coefficients ( $R^2$ ) in Table 3. By comparing the slopes for the two time regimes for mixtures 2 and 3 to those for the control mixture 1, an



indication of the shrinkage reduction can be determined. In this regard, mixture 2 is slightly more efficient at reducing the shrinkage than mixture 3 at early times, but is less efficient at longer times. This would be consistent with the delivery mechanism for the shrinkage-reducing admixture employed in the two mortars. In mixture 2, the shrinkage-reducing admixture is present in the mixing water and will influence drying shrinkage greatly at early times and less so at later times, as the admixture is absorbed by cement hydration products, etc. In mixture 3, the shrinkage-reducing admixture is drawn into the mixing water (from the solution in the LWA particles) during the course of the hydration. *Thus, in comparison to admixture delivery by conventional means, FLAIR delivery may be inefficient at early times (since some of the admixture is still located in the LWA particles and not in the bulk water), but it may be more efficient at longer times as less of the admixture is absorbed by the cement hydration products.*

Table 3. Slopes of shrinkage vs. mass loss for the three mortar mixtures.

	3-7 days slope	> 7 days slope	3-7 days $R^2$	> 7 days $R^2$
Mixture 1	515.975	330.019	0.997	0.987
Mixture 2	267.280	331.470	0.987	0.982
Mixture 3	305.700	280.392	0.996	0.996

#### Summary:

In summary, the following observations apply to a comparison of the delivery of a shrinkage-reducing admixture by conventional means (addition to bulk mixing water) vs. addition via FLAIR technology:

- 1) the air detaining properties of the shrinkage-reducing admixture may be lessened by its addition via the LWA particles as opposed to in the bulk mixing water,
- 2) addition via FLAIR technology provided equivalent performance to addition via conventional means with respect to degree of hydration, compressive strength development, and reduction in autogenous shrinkage, and
- 3) based on the analysis of slopes summarized in Table 3, addition via FLAIR technology provided less drying shrinkage reduction at early ages (3 days to 7 days), but provided a greater reduction at later ages (7 days and beyond).

Figure 1. Degree of hydration and compressive strength development (each point is the average of three specimens) for the three mortar mixtures.

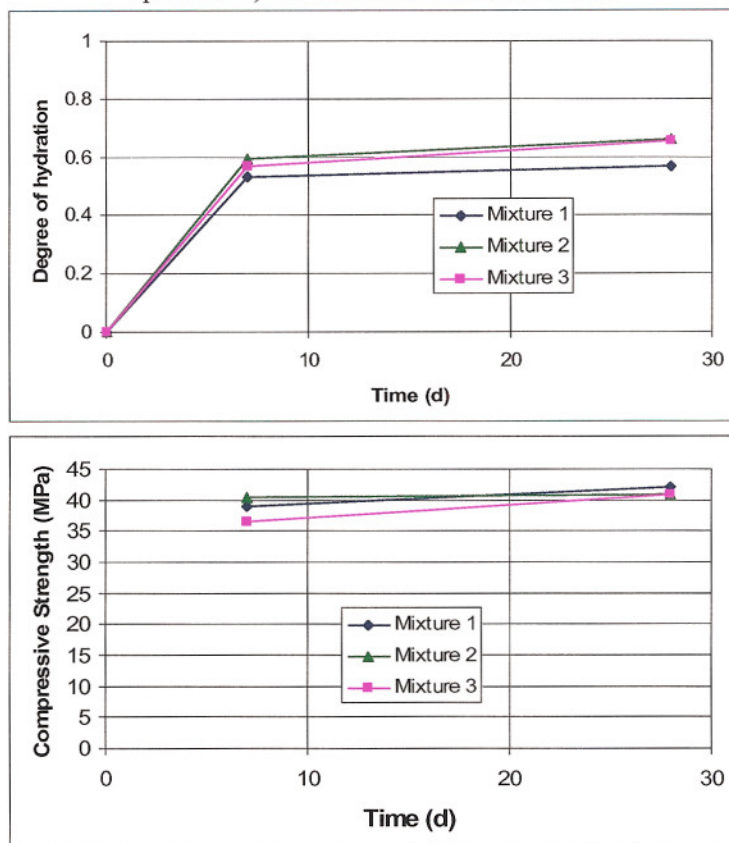


Figure 2. Autogenous shrinkage/expansion for the three mortar mixtures. Each curve shown is the average of two specimens.

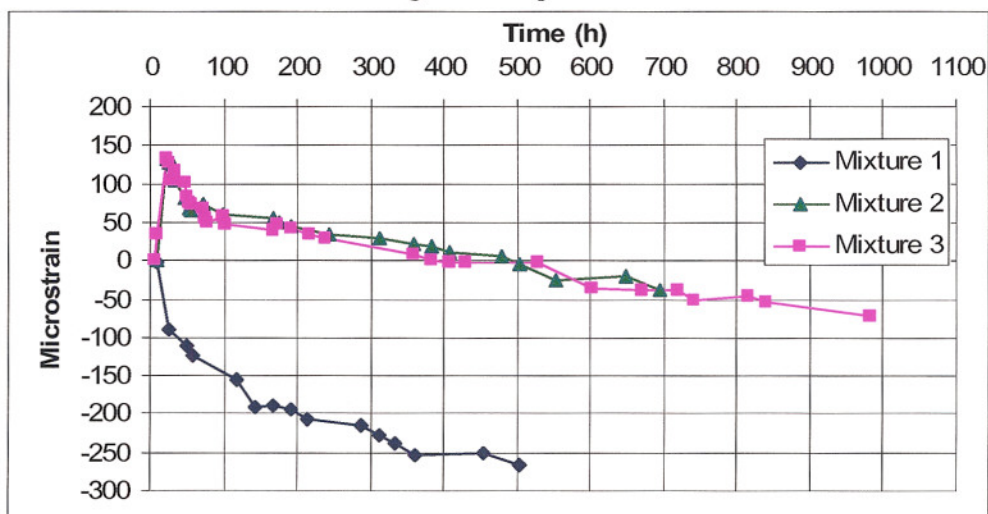
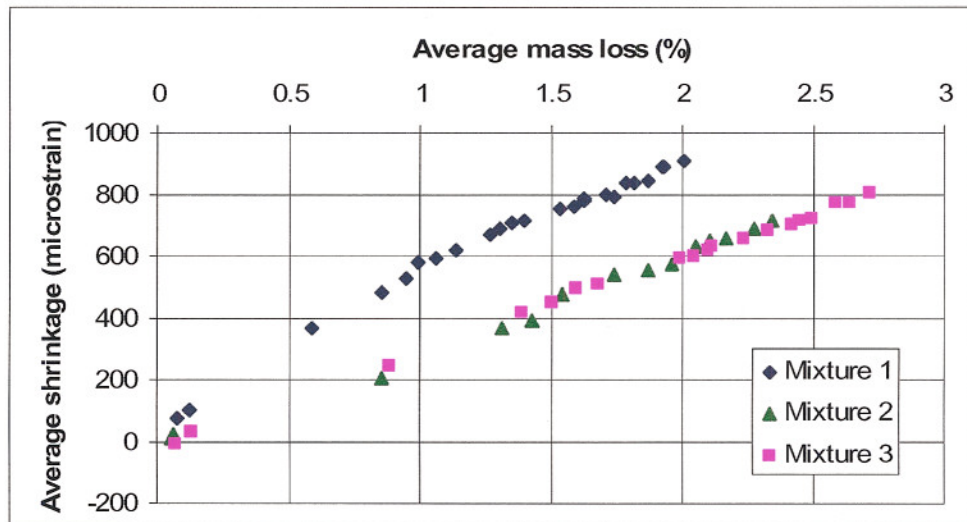


Figure 3. Drying shrinkage vs. mass loss for the three mortar mixtures.



Reference:

1) D.P. Bentz, M.Geiker, and O.M. Jensen, "On the Mitigation of Early Age Cracking," in Report TVBM-3104, Self-Desiccation and Its Importance in Concrete Technology, Eds. B. Persson and G. Fagerlund, Lund Institute of Technology, Lund, Sweden, 2004, pp. 195-203.