

BROWARD COUNTY BEACH DEMONSTRATION PROJECT

LITERATURE REVIEW

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**Broward County Office of Integrated Waste Management
Broward County Department of Planning and Environmental Protection**

Submitted by:

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1 INTRODUCTION

Broward County has conducted numerous beach nourishment programs since the early 1960's because its beaches are in a chronic state of erosion. Significantly, 21 of the 24 miles of Broward beaches are defined as critically eroded (FDEP, 2000). A 1.3 million cubic yard nourishment project will dredge sand from offshore and place it on Hollywood Beach, Hallandale Beach, and John U. Lloyd State Park Beach in 2005 (CPE & Olsen, 2003). This project has been optimized for a renourishment interval of 6 years (CPE & Olsen, 2003). Because localized areas of higher relative erosion rates (erosional hot spots) may jeopardize the project, the addition of glass cullet as emergency beachfill may extend the life of the project by nourishing these areas with smaller volumes of fill.

Current sand sources include inter-reefal sedimentary infills offshore, upland dune and sand sheet deposits from inland parts of Broward County, and aragonite sand from the Bahama Banks. Using recycled glass as a potential alternative source material for beach fill (Edge, 2002) may help alleviate demands for sediment. Because glass cullet retains physical properties that are similar to natural silica sand, it may prove to be a viable alternative beachfill material (Finkl, 1996). Glass cullet has many advantages as potential emergency beach fill material which include:

- (1) The ability to mechanically select grain sizes comparable to the native beach characteristics that will stabilize the beach.
- (2) The chemical, mechanical, geologic, and engineering properties of glass cullet are similar to natural sand.
- (3) The ability to utilize a cost-effective, readily available recycled product.
- (4) Utilization of an environmentally safe, inert material.
- (5) Consistent supply of source material.
- (6) Consistent demand for beach fill.

The Broward County Solid Waste District processed 15,840 tons of glass in 2004 at cost of \$145,000 (Austin, 2004). Although revenue is generated by recycling clear and brown glass, mixed and green glass product are usually a greater fraction of the glass collected. The mixed and green glass are transported to the landfill for use as cover material. Finding a more beneficial use for mixed and green glass may improve the economics of the recycling program.

Due to the limited secondary materials market and increasing cost of recycling glass, the Broward County Office of Integrated Waste Management (OIWM) conducted a pre-feasibility study on using recycled glass as beach fill material (Malcolm Pirnie, 2003). This study concluded that this was a viable concept and recommended that further studies be conducted. A feasibility study for Moonlight Beach, CA conducted by Woodward-Clyde (1993), also showed that glass cullet was a viable beach compatible material.

2 CURRENT RECYCLED GLASS SUPPLY

The Office of Integrated Waste Management for Broward County estimated that 15,841 tons of glass was recycled through public and private recycling efforts in FY2004. This was an increase from 2002 and 2003 when 12,538 and 12,894 tons of glass were respectively recycled (Austin, 2004). While glass makes up 3% of the total solid waste stream, an estimated 70,000 tons of glass is potentially recoverable (Bresee, 2004).

In Broward County, approximately 43% of the glass collected is sorted and transported to Strategic Materials, Inc. (Sarasota, FL) for final processing. The remaining 57% of the glass is composed of glass that could not be sorted by color, as the pieces were too small. These bottles are broken further by handling and shipped to the local landfill for use as cover material (Austin, 2004). This fraction (9,024 tons in 2004) can potentially be processed into beach compatible material, if the material satisfies the current environmental requirements.

The Solid Waste Authority (SWA) in Palm Beach County recycled 14,334 tons of glass in 2003 (SWA, 2003). Green and mixed glass comprised 10,233 tons of this total and was used for daily landfill cover (instead of soil), drainage aggregate around underground pipes, or as mulch medium in landscaped areas. The remaining 4,100 tons of glass (clear and brown) was sold to private companies and incorporated into hot mix asphalt to create a paving mixture termed "glassphalt" (Kandahl, 1992). Florida's Department of Transportation has approved use of glassphalt on Florida's highways, thus expanding the market for the use of waste glass material (Kerwin, 1997).

The estimated annual volumetric need along Broward County's beaches is approximately 643,000 cubic yards/year (CPE & Olsen, 2003). There is not sufficient volume of glass cullet to meet this need, given that 9,024 tons of recycled glass was potentially available for beach fill in 2004 (one cubic yard of glass cullet weighs approximately one ton). However, glass cullet can be strategically placed in erosional hot spots to create a more stable beach, which in turn theoretically extends the life of the Broward County Shore Protection Project, which uses inter-reefal beach compatible sand for restoration activities.

3 ECONOMIC EVALUATION

Costs associated with using recycled glass in Broward County are favorable to other alternative beach fill materials. In 2004, Broward County spent \$128,200 to transport and dispose of 9,025 tons of mixed glass generated at the material recovery facility (Austin, 2004), which corresponds to \$14.20 per ton of glass cullet and previously was as high as \$24 per ton.

The feasibility of investing in equipment to process recycled glass to beach compatible material was considered by Malcolm Pirnie (2003). Their economic evaluation to determine the net present value of such an investment by Broward County resulted in a pre-feasibility report that compared two glass pulverizing systems, one from Glass Aggregate Manufacturing Equipment, and the other from Andela Products. The analysis suggested that the cost of implementing and operating a facility to produce glass cullet for beach application would be similar to the cost of

the current beach nourishment program. The Malcolm Pirnie pre-feasibility report highlighted the following benefits of the County having its own pulverizing facility:

- (1) The project would be economically feasible because the cost would be similar to the current shore protection program.
- (2) Costs would be internalized within the County structure and not be subject to cost variations in the glass recycling market.
- (3) The County would have greater control over the cost to recycle recovered glass.
- (4) The County could cater to more than one end-use market.
- (5) There would be economic benefit in deferred costs if the county did not have to buy sand.
- (6) Erosional hot spot control using glass cullet would be viewed as a “green” project.

Woodward-Clyde Consultants (1993) considered the cost of processing recycled glass for placement on Moonlight Beach in the City of Encinitas, California, where approximately 1,200 tons of sand per year were imported at a cost of about \$21/ton. They estimated that it would be difficult to achieve a delivered cost of \$20/ton for recycled glass on Moonlight Beach because mixed glass leaving the recycling plant would cost \$11/ton and the material would then require further processing to glass cullet and transport to the beach.

4 COMPATIBILITY OF GLASS CULLET AND BEACH SAND

A concern associated with the use of recycled glass on beaches relates to the assimilation of cullet by beach sediments. The general physical characteristics of glass cullet compared to native beach sand was comprehensively reviewed by Kerwin (1997). Table 1 summarizes the compatibility of glass cullet and natural beach sand based on physical characteristics and shows that glass cullet is compatible with beach sand.

Table 1
Compatibility of Glass Cullet and Beach Sand based on Physical Properties (Kerwin, 1997).

Test	Compatible with Sand	Comments
Mean grain size	Yes	Processed to a wide range of specified sizes.
Sorting	Yes	Varies, dependent on grain size criteria.
Sphericity	Yes	Low, flat, oblate, and bladed shapes provide stability as beach fill material.
Roundness	Yes	Angular shape quickly abraded by littoral action.
Color beach	Yes	Varies with source (like sands) pale yellow-light brown.
Specific Gravity (Relative Density)	Yes	Cullet=2.49 to 2.65; natural aggregate = 2.68; silica-silicon dioxide = 2.21 to 2.32; quartz = 2.65.
Gradation	Yes	Shows little or no gradation.
Particle Shape (Workability)	Yes	Suitable for mechanical handling, low potential for punctures and cuts.
Durability	Yes	Less than crushed rock but close to normal limits for roadway aggregate.
Compaction	Yes	Little or no gradation changes, compaction curves are relatively flat, material insensitive to moisture content.
Permeability	Yes	Medium to high permeability corresponding to medium sand and gravel aggregate.
Thermal Conductance	Yes	Slightly lower than natural aggregates, cullet conducts heat somewhat more slowly.
Shear strength	Yes	Cullet exhibits good to excellent CBR values; cullet has resilience moduli >29 ksi at a bulk stress of 25 psi.

Coarse glass cullet can be treated so that particle sizes fall within the range of local beach sand, as discussed in the analysis of glass cullet particle size and shape by Woodward-Clyde (1993). Natural abrasion and comminution of glass particles in the surf zone will make grains less angular, a process that negates concerns over initial particle angularity and sphericity. Mechanical sorting, tumbling, or other processing of crushed glass material prior to placement also produces rounded grains. Woodward-Clyde (1993) concluded that recycled ground glass is generally suitable as beach fill because: (1) it physically (grain size, color) resembles natural beach sands, (2) it can be ground to a particle-size range that is compatible with local beach sand, and (3) the cullet can be imperceptibly blended with natural sand. They also found that the specific gravity of crushed glass ranged from 2.5 to 2.8, bracketing the specific gravity of natural quartz (silica) at 2.7.

Kerwin (1997) also presented analyses of sand from Broward County's beaches that was compared with glass cullet in terms of grain size, roundness, sphericity, sorting, and Munsell color. Comparisons were performed on a native beach sand sample, glass cullet and two composite samples (67% sand / 33% glass cullet, and 91% sand / 9% glass cullet). The results are summarized in Table 2.

Table 2
Physical Properties of Study Site Beach Sand, Glass Cullet, and Beach Sand/Glass Cullet Composites (after Kerwin, 1997).

Test Conducted	Study Site Sand	Glass Cullet	67% Sand, 33% Glass Cullet	91% Sand, 9% Glass Cullet
Sphericity	Oblate low	Oblate-bladed low	Oblate low	Oblate low
Roundness	Round	Angular/subround	Round	Round
Mean grain size	0.49	0.78	0.46	0.44
Sorting	mw	m	mw	mw
Munsell Color Notation				
Dry	7.5YR 7/4 to 10YR 8/3	5Y 8/3	10YR 7/2	2.5Y 7/2 to 5Y 7/2
Moist	7.5YR 7/2 to 10YR 7/3	5Y 7/3	10YR 6/2 to 5Y 7/2	2.5Y 7/4

*m=moderately sorted, mw=moderately well sorted

5 PERFORMANCE COMPARISON OF GLASS CULLET AND BEACH SAND

Recent studies conducted at Texas A&M University compared the performance characteristics of recycled glass to natural sand (Edge, 2002) in physical model experiments where a 3-D wave tank generated regular waves. The tank was divided into two channels: one for a glass beach and the other for native beach sand. Six tests measured beach profile change due to wave action in the tank. Beach profiles were measured along the centerline of both channels at three different times: 15, 60, and 120 minutes of wave action. At the end of the test, glass cullet and native beach sands were found to have the same performance characteristics for the conditions tested. The wave reflection coefficient for glass cullet was less than native beach sand, suggesting that glass cullet absorbs energy better than sand.

Also investigated was the rate of abrasion and loss of mass through abrasion (Edge, 2002). A tumbler machine was used to simulate wave action, current, and wind. This experiment measured mass loss for two samples: one was glass only and the other was a mixture of glass plus sand. The latter combination was an attempt to simulate real world effects where the glass cullet and sand are mixed. The glass and sand/glass samples were placed in the tumbler machine with water. After several days of tumbling, the samples were sieved and dried. Grain sizes less than sieve #200 were removed from the sample. Masses were measured after 7, 14, and 36 days of tumbling. These tests showed that the glass-only sample had a very high initial rate of abrasion, but the rate eventually stabilized and was comparable to the glass/sand mixture.

6 PERMITTING

The Florida Department of Environmental Protection (FDEP) is the primary state regulatory agency that oversees beach reconstruction activities in Florida. The placement of glass cullet on a beach has not been previously permitted in Florida. No literature could be found on the permitting requirements of glass cullet beaches elsewhere in the U.S. However, the placement of

beach fill alternatives, such as aragonitic oolite, have been permitted and constructed in Florida, as reported in Section 8 of this report.

The permitting compliance requirements of a beach nourishment project in Broward County were reviewed by Kerwin (1997). Table 3 summarizes FDEP Chapter 62B-41, Rules and Procedures for Application for Coastal Construction Permits, Section 62B-41.007 Design, Siting and Other Requirements.

Table 3
FDEP Requirements for Permitting Beach Nourishment (Kerwin, 1997)

FDEP Regulation	Glass Cullet Properties	Complies?
Grain size < 5% fines	Ground to specified grain sizes < 5% fines	Yes
Grain size of <5% rock and gravel	Ground to specified grain sizes <5% gravel	Yes
Similar composition	Amorphous silica	Yes
	Similar to 50% quartz component	
Similar coloration	Varies with source	Yes
	Pale yellow-light brown	

The FDEP supports new and innovative approaches for shore erosion control and has provided funding for the Broward County Beach Demonstration Project. The governing guidelines for experimental coastal construction are contained in Section 62B-41.0075, Florida Administrative Code. Components of the relevant sections are summarized below:

- (1) The proposed location must be in an erosion area as identified in the Department's Beach Restoration Management Plan.
- (2) The proposed location must be properly suited for a non-biased comprehensive analysis of the results of the proposed coastal construction and must include sufficient control sites where comparative monitoring data can be obtained which is not influenced by the proposed new technology.
- (3) The proposed location must be situated in an area, which is not considered to be an environmentally sensitive area by the Department.
- (4) The project must be supported by adequate scientific, engineering and design theory or experimental data demonstrating that it has the potential to provide a positive benefit to the coastal system and is not expected to result in a significant adverse impact. The size and scope of the field test shall not exceed that necessary to adequately address the test plan objective. The requirement for supporting experimental data shall be waived by the Department if it finds that the proposed project has minimal potential for adverse impact.
- (5) Requests for permits under this rule must be presented by a riparian property owner or governmental entity.
- (6) The Department may confer with a special scientific third party consultant to assist in the review of such proposed projects, to oversee the experiments and to provide an assessment of results and appropriate recommendations.
- (7) The applicant shall present a test plan to the Department for review.

- (8) The Department shall require assurances such as a mitigation program, financial instrument, or contractual agreement to assure compliance with the permit conditions.
- (9) Any time the Department determines that the project must be removed under the provisions of this chapter, the permittee shall also be responsible for restoring the area of installation and any adversely affected areas to pre-project conditions. All costs of removal and restoration shall be borne by the permittee.
- (10) All new technologies shall be designed to be stable and durable in the coastal environment.

A U.S. Army Corps of Engineers (USACE) permit will also be required if the beach cullet is placed seaward of the mean high water line, per Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. Initial placement of material landward of the mean high water line for research purposes will not require a USACE permit, but may require authorization from the U. S. fish and Wildlife Service under the provisions of the Endangered Species Act due to the potential affect on listed marine turtle species during nesting season.

7 EXAMPLES OF GLASS CULLET BEACHES

Curaçao, Netherlands Antilles

Glass cullet has been placed on two beaches on the Caribbean island of Curaçao, at the Hilton Hotel on Piscadera Bay (southern coast near downtown Willemstad) and at Zanzibar Park (also on the southern coast). Grain sizes of the cullet placed on these beaches ranged from 0.20 mm to 0.60 mm (Paardekooper, 2004). The materials placed on Curaçao's beaches have similar physical properties in terms of grain size and color to those proposed for Broward County's Beach Demonstration Project.

The volume of glass cullet placed at the Hilton Hotel is unknown, but approximately 110 cubic yards of glass cullet was mixed with native beach sand in a 1,000 square foot area at Zanzibar Park (Paardekooper, 2004) along with a control section of pure cullet. According to Paardekooper (2004), beachgoers preferred the beach sand - glass cullet mixture compared to the control plot with only glass cullet. This study noted, however, that visitors did not distinguish between sections of the beach that had varying ratios of natural sand to glass cullet. Turtle nesting occurred at both sites but there is no official data available from the local government agency regarding nesting or hatching success (Paardekooper, 2004).

Lake Hood, New Zealand

The Town of Lake Hood created a beach using recycled glass cullet to encourage recycling and to increase environmental awareness (Temple, 2004). The lake is man-made, and WasteBusters Trust Canterbury constructed a beach for a festival in January 2003. The "Crystal Beach," composed entirely of glass cullet, is reported to look and feel like natural sand (WasteBusters, 2004). The beach was popular with the public and a sand sculpture competition was incorporated into the festival (Photo 1). However, according to the *Ashburton Guardian* (2004) newspaper, some glass cullet coarser than 5 mm, including some pieces with sharp edges, was deposited on the lake beach. YMCA volunteers were able to remove the coarse fragments in

response to safety concerns. This project highlights that a glass cullet beach is feasible but that quality control is an integral part of the project. The glass cullet placed at Lake Hood (New Zealand) and Curaçao (Caribbean Sea) resembles natural sand, which is the concept of the Broward County Beach Demonstration Project.



Photo 1. Sand sculpture on a glass cullet beach, Lake Hood, New Zealand (Temple, 2004).

8 EXAMPLES OF GLASS PEBBLE BEACHES

Fort Bragg, California

In 1949, the town of Fort Bragg (northern California) started disposing of waste (including cars and refrigerators) by dumping it off a local cliff above a beach. This practice was terminated 20 years later after adverse environmental impacts of these activities were recognized. The larger waste items were removed but, over time, the organic materials decomposed and wind and wave action eroded other materials. The combination of cleanup efforts and natural process left polished bits of broken glass mixed with beach sand to form what is now known as “Glass Beach” (Photo 2). Photo 3 shows a variety of multi-colored glass pebbles next to a 1 mm (0.04 inch) scale. Although fragments of glass at Glass Beach are much larger (>1.0 mm) than what is proposed in the Broward County Demonstration Project, this site is mentioned because of its popularity.



Photo 2. "Glass Beach" at Fort Bragg, California (City of Fort Bragg, 2004).



Photo 3. Pebbles on Glass Beach, Fort Bragg (City of Fort Bragg, 2004).

Kauai, Hawaii

Near the Town of Port Allen on the island of Kauai, Hawaii, there is a beach composed of winnowed glass fragments. Also called “Glass Beach,” the site was a former dumping ground for glass bottles. Reworked by wave action, the glass has been comminuted and reduced to pebble size. Photo 4 shows the smooth, multi-colored glass pebbles along Glass Beach.



Photo 4. Glass pebbles at Glass Beach on Kauai, Hawaii (Schneider, 2001).

9 ARAGONITE AS AN ALTERNATIVE BEACH FILL MATERIAL

Oolitic aragonite sand is crystallized calcium carbonate, which is formed by the deposition of calcium carbonate around a nucleus, usually a shell fragment, foraminiferal test, fecal pellet, or other carbonate particle. (Newell *et al*, 1960). Aragonite deposits are generally made up of smooth, rounded, moderately well sorted particles. Aragonite has been previously permitted for placement on beaches in Florida by the FDEP, as an alternative beach fill material. It is therefore useful to discuss the properties of aragonite and why it is considered beach compatible.

An alternate sand source investigation was conducted for Dade County, Florida beach erosion control projects (CPE, 1997). An aragonite sample, received from Marcona Ocean Industries (Ocean Cay, Bahamas), had a mean grain size of 0.31 mm. CPE concluded that the aragonite sand was compatible with beach sand within Dade County. Preliminary studies and monitoring results suggested that an aragonite beach might erode at a slower rate than a native sand beach having similar grain size characteristics (Monroe, 1969). Split flume wave tank tests showed that equilibrium beach profiles were essentially the same for aragonite and hydraulically equivalent quartz sands.

Pepper Park, St. Lucie County, Florida

In 1965, during a developmental program to extract oolite from the Bahama Bank by Union Carbide Corporation (New York), it was discovered that aragonitic sand had properties that might make it an attractive beach nourishment material (Cunningham, 1966). These properties are as follows:

1. Grain Size - the larger grain size of Bahama Bank oolite (0.3 mm) compared with that of natural beach sand (0.2 mm) provides a steeper and more stable foreshore.
2. Grain Sphericity - the higher sphericity of aragonite sands reduces grain movement in turbulent waters.
3. Specific Gravity - the greater relative density of aragonite (2.88) compared to quartz sand (2.65) produces faster fall velocities and greater resistance to motion in currents.
4. Natural Adhesion - aragonite sands have a natural adhesive quality that provides greater resistance to erosion.
5. Gradation - aragonite sands tend to be finely sorted with no pebbles; or silt / clay fraction, which are typically washed away quickly (up to 30% loss).
6. Color – white colored aragonite sand does not absorb as much solar radiation as darker quartz sand.
7. Availability - there is 30 to 50 billion tons of oolite on the Bahama Banks.

Union Carbide evaluated the feasibility of using aragonite on Florida beaches and Pepper Park, approximately two miles north of Fort Pierce Inlet (St. Lucie County, Florida), was used as a test beach for placing oolite. Pepper Park Beach native sands were of similar grain sized as the oolite, making the beach suitable for these tests. One thousand tons of aragonite sand and beach sand were placed on the foreshore of Pepper Park Beach in 1966. Placement occurred near the end of a six-month period (September through February) of slight accretion caused by swells that set up a southerly drift. The placed material was naturally washed by waves before additional material was added. The beach slope was graded by natural wave action, rather than artificial means. Based on the results of daily inspections, the aragonite appeared to be more stable than the native sand (Cunningham, 1966).

Wanless (1983) compared the particle size and grain-size distribution of oolitic sand samples from the Bahama Bank to sands from potential borrow areas in southeast Florida, including Pompano Beach, Lake Worth, Jupiter, and Ocean Ridge. The results of mechanical analyses and Stokes settling velocity tests indicated that the oolite was coarser (> 0.35 mm) and sands from Jupiter and Ocean Ridge were the finer (< 0.20 mm). The coarser oolite (39.6% greater than 0.35 mm) is suitable for “moderate energy” beaches along the southeast Florida coast.

Fisher Island, Florida

Fisher Island was the first large-scale use of aragonite for beach restoration in the United States (Bodge and Olsen, 1992). Approximately 30,000 cubic yards of oolitic aragonite sand was barged from the Bahamas and placed above the mean high water line on Fisher Island, FL between December 1990 and March 1991. Seven groin structures were also used to stabilize the beach fill project area. Preliminary data from sea turtle monitoring studies suggested that the aragonite was approximately 2°C cooler than a Florida sand test plot. However, histology was not permitted to determine if this affected turtle gender.

Effects on Sea Turtles

The effects of alternative sands on sea turtle nests and nesting is a contentious issue. A hatchery study conducted by Blair *et al.* (2000) during three nesting seasons from 1995 to 1997 tested general nest success parameters, temperature, and sex ratios. The study was conducted at a hatchery on Miami Beach using the following sand samples: Offshore carbonate sands, aragonite (Bahama Bank, Bahamas), and quartz (from an inland quarry in central Florida). The offshore carbonate and quartz sands were significantly warmer than the aragonite sand (used as the control in the experiment) but there was little difference in the temperature between the offshore carbonate and quartz sands. No significant differences were found among hatching and emergence success for the different sand samples. Turtle nests had longer incubation periods in the aragonite sands, while the incubation period was similar within the offshore carbonate and quartz samples (Blair *et al.*, 2000). The ratio of the male hatchlings in the different sand samples varied from 42% to 53%. There was no significant difference in percent males found for nests in the different types of sand, though the variability of sex ratios within each nest was high (Nelson *et al.*, 1998).

10 SUMMARY

Glass cullet can meet specifications for beach compatible material based on grain size, sorting, and color. The present production of glass cullet is insufficient to fulfill all volumetric needs of Broward County's beach nourishment program. However, strategic placement of glass cullet in erosional hotspots, where coarser grain sizes increase beach stability, can enhance the performance of the Broward County Shore Protection Project. While no glass cullet beaches have been constructed in the U.S., two international examples show that beach users react favorably where glass cullet was used as fill material.

11 REFERENCES

Ashburton Guardian, 2004. *Crystal Beach Sifted*.

<http://www.ashburtonguardian.co.nz/index.asp?articleid=2190>.

Austin, N., December 2004. *Personal communication* (e-mail correspondence). Broward County Office of Integrated Waste Management, Fort Lauderdale, Florida.

Blair, S.M.; Nelson, D.; Cheeks, R.; Hibler, J.; Gross, T.; Lutz, P., and Hoover, J., 2000. Evaluation of quartz, aragonite and carbonate beach compatible sand on nest temperature and success parameters of *Caretta Caretta* nests in southeastern Florida, USA. *Proceedings of the 18th International Sea Turtle Symposium*, US Department of Commerce, NOAA Technical Memorandum NMFS-SEFSC-436, pp.178-180.

Bodge, K.R., and Olsen, E.J., 1992. Aragonite Beachfill at Fisher Island, Florida. *Shore and Beach*, pp 3-8.

Bresee, P. November 2004. *Personal communication*. Recycling Program Manager, Broward County Office of Integrated Waste Management, Fort Lauderdale, Florida.

City of Fort Bragg, 2004. http://www.fortbragg.com/glass_beach/.

Coastal Planning & Engineering, Inc., 1997. *Dade County Alternate Sand Source Investigation*. Boca Raton, Florida: Coastal Planning & Engineering, Inc.

Coastal Planning & Engineering, Inc. and Olsen & Associates, 2003. *Broward County, Florida Shore Protection Project, Segments II & III, General Reevaluation Report with Environmental Impact Statement*. Boca Raton, Florida: Coastal Planning & Engineering, Inc. and Olsen & Associates.

Cunningham, R. T., 1996. Evaluation of Bahamian oolitic aragonite sand for Florida beach nourishment. *Shore and Beach*, pp. 18-21.

Edge, B.L.; Cruz-Castro, O., and Magoon, O.T., 2002. Recycled glass for beach nourishment. *Proceedings of the 28th International Conference on Coastal Engineering*, World Scientific, Vol. 3, pp. 3630-3641.

Finkl, C.W., 1996. Beach fill from recycled glass: a new technology for mitigation of localized erosional 'hot spots' in Florida. *Proceedings of the 9th National Conference on Beach Preservation Technology*, Tallahassee, Florida: Florida Shore and Beach Preservation Association, pp. 174-175.

Finkl, C.W. and Kerwin, L., 1997. Emergency beach fill from glass cullet: an environmentally green management technique for mitigating erosional "hot spots" in Florida. *Proceedings of the 10th National Conference on Beach Preservation Technology*, Tallahassee, Florida: Florida Shore and Beach Preservation Association, pp. 304-319.

Florida Department of Environmental Protection, 2000. *State of Florida Strategic Beach Management Plan*. Florida Department of Environmental Protection, Tallahassee, Florida.

Kandahl, P.S., 1992. *Waste Materials in Hot Mix Asphalt – An Overview*. National Center for Asphalt Technology, Auburn University, Georgia, NCAT Report No. 92-6.

Kerwin, L., 1997. *Potential Applications for Recycled Glass in Beach Management: Emergency Stabilization of “Hot Spots” in Broward County, Florida*. Boca Raton: Florida Atlantic University, Master’s thesis.

Malcolm Pirnie, Inc, 2003. *Beach Renourishment Pre-Feasibility Study*. Fort Lauderdale, Florida: Malcolm Pirnie, Inc.

Nelson, D.A.; Blair, S., and Gross, T.S., 1998. Preliminary assessment of loggerhead turtle (*Caretta caretta*) nest sex ratios of nests incubated in aragonite sand. *Proceedings of the 16th Annual Symposium on Sea Turtle Biology and Conservation* (Miami, Florida). US Department of Commerce, NOAA Technical Memorandum NMFS-SEFSC-412, pp. 110-112.

Newell, N.D., Purdy, E.G. and Imbire, J., 1960. Bahamian Oolitic Sand. *Journal of Geology*. pp 481-488.

Paardekooper, Williem-Jan, November 2004. *Personal correspondence*. Curexglass Sales, Curaçao, Dutch Antilles.

Schneider, A., 2001. <http://adamschneider.net/kauai2001/>.

Solid Waste Authority of Palm Beach County, Florida, 2003. *Adopted Fiscal Year 2003/04 Budget*. Solid Waste Authority of Palm Beach County.

Souder, G., December 2004. *Personal communication*. Olimar Sand and Gravel, Miami.

Temple, I., November 2004. *Personal communication* (e-mail correspondence). Event Management Services. Auckland, New Zealand.

Wanless, H. R., 1983. *Comparative Grain Size Analyses of an Oolitic Sand and Sands from Potential Borrow Areas in Southeast Florida*. Arthur V. Strock and Associates, Inc.

WasteBusters Trust Canterbury, 2004. <http://www.wasterbusters.orcon.net.nz/crystal-beach.html>.

Woodward-Clyde Consultants, 1993. *Feasibility Study of Recycled Ground Glass Beach Sand for the City of Encinitas*. San Diego, California.