Final Report

Demonstration Project:
Mitigation of NPS Impact to Littoral Zone of Lake Thunderbird Cleveland County, Oklahoma

Lake Thunderbird FY- 00 319

October 24, 2005

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Agency: Oklahoma Water Resources Board (OWRB)

Project Title: Demonstration Project: Mitigation of NPS Impact to Littoral Zone of Lake Thunderbird Cleveland County, Oklahoma

Task: 1100, Grant # C9-996100-08

Project Location: Lake Thunderbird, WBID 520810000020, HUC11090203010

PROBLEM STATEMENT:

Lake Thunderbird is listed as impaired on the State's 303(d) list (WBID 520810000020) by suspended solids. The Oklahoma 319 Non-Point Source (NPS) Assessment report shows that there are no point source discharges in the watershed; thus all pollution problems originate from non-point sources. A low cost, low maintenance means to control the suspended solids within Lake Thunderbird is needed. Addressing Lake Thunderbird shoreline erosion is a first step towards remediation of the in-lake suspended solids problem.

Suspended solids, whether washed in from the drainage basin or re-suspended in the reservoir, serve to prevent or eliminate the establishment of an aquatic plant community in the littoral zone. Littoral plants are essential to a healthy functioning reservoir ecosystem. Littoral aquatic plants divert nutrients from algae production by absorbing nutrients from the water column during the growing season (**James & Barko, 1990**) and providing direct food and aquatic structural habitat for fish (**Smart, et.al., 1996**). The loss of an aquatic plant community also accelerates the physical process of shoreline erosion (**USACE, 1990**). Once physical processes such as shoreline erosion have begun in Oklahoma reservoirs it often takes human intervention to stabilize the shoreline long enough to establish the littoral zone as a functioning community. Bioengineering methods have been developed that halt the erosive processes long enough to allow for the establishment of a healthy aquatic plant community. This results in low-cost long-term erosion control.

PROJECT OBJECTIVES:

This project's primary objective was to demonstrate to the Central Oklahoma Master Conservancy District (COMCD), Lake Thunderbird State Park and Bureau of Reclamation, cost-effective bioengineered erosion control methods for reducing shoreline erosion and the impact of NPS pollutants, most notably suspended solids. Although bioengineering has been around for many years, its methods and advantages are virtually unknown to most Oklahoma lake managers. The project demonstrated multiple protective shoreline treatments. The OWRB in cooperation with lake managers, worked to find the best methods and sites to demonstrate bioengineering methods.

A secondary objective was to provide Lake Thunderbird Managers a lake-wide erosion control plan to incorporate into future projects using these or other bioengineering methods.

This project was not intended to solve NPS problems in the drainage basin nor treat the entire 86 miles of the lake's shoreline.

PROJECT FINDINGS:

Branchboxes and CGRs can work as breakwaters but other methods that may be easier to employ should also be considered at Lake Thunderbird.

While problems occurred with some portions of the breakwaters, the 150' of effective breakwater has established a dense stand of softstem bulrush, common bulrush and waterwillow found behind the remaining branchbox breakwaters. Without a contiguous breakwater, growth out from behind the branchboxes will be slow but should occur over time. Barring herbivory, further severe drought or other adversity, permanent shoreline protection will develop from natural spread of these aquatic macrophytes.

This demonstration project has shown that bioengineering methods for erosion control in Lake Thunderbird are a viable alternative for lake managers. The outstanding vegetative reproduction of plants behind the project breakwater demonstrated that aquatic macrophytes could be established even in a poor quality gravel substrate. Continued observation will be necessary to confirm that these plants will: continue to fill in the shoreline as the branchbox gives way, survive the wave action, dissipate wave energy to the site.

PROJECT TASKS:

TASK 1: DEVELOP SHORELINE EROSION CONTROL PLAN

Deliverables: Shoreline Erosion Control Plan for Lake Thunderbird. Completed December 27, 2001.

A three tiered approach was taken: 1) review literature and data sources; 2) coordination with Oklahoma Tourism and Recreation Department (OTRD) personnel; and 3) a field survey by boat to examine the lake's shoreline. Review of literature and data sources included looking at the Cleveland County Soil Survey (USDA Natural Resources Conservation Service, 1987), climatic data (NOAA, 2001) and hydrologic data (USACE, 2001). The field reconnaissance was conducted by both land and boat on September 17 – 19, 2001. The plan was written by AllEnVironment Consulting, finalized December 27, 2001 and delivered to EPA in February 2002.

From the erosion control plan came the following substantive conclusions applicable to this project:

"It is recommended that since erosion is so extensive, sites be prioritized for erosion control as mentioned above. Higher priority should go to sites where structures or facilities, such as picnic tables and grounds, are threatened… It is suggested that one start with less severe sites first for illustrating success and then proceed to more difficult reaches of shoreline."

Site selection took into consideration several factors: easy access to bring in materials, significant public exposure near a marina, moderate fetch to demonstrate the need for a breakwater and a high chance for success of bioengineering efforts. A secondary advantage of the selected site was to show that breakwaters will not only protect the shore and plantings from waves but will actually serve as an instrument for sediment accretion. Most aquatic plants need a silt-like substrate to root in and take hold but it is not necessary that the site itself have excessive amounts of silt. It is possible, with the help of a good breakwater that suspended solids will settle out in the calmer waters behind them creating a site capable of supporting aquatic plants.

Project Site Description:

The demonstration site is located east of Calypso Cove Marina on the south shore of Lake Thunderbird (Figure 1). There is an asphalt road to the marina that is within 10 feet of the top of the eroded bank at its closest point. While there is no immediate threat to the road, the erosion could become a problem over the next several years. The constructed breakwater length is 425 feet. The average width of the site from the toe of the bank to the breakwater is 28.5 feet giving a calculated plantable area of 12,110 square feet. At normal pool elevation, erosion is visible from the waterline back to nearly vertical banks in some areas (Figure 2). Between the banks and the water's edge is a wide, eroded beach of clay and rock (Figure 3).

Above the site is an old roadbed that, while not in use, is threatened by scour. The taller more vertical escarpment on the western end approaches 9 ft. in height. The escarpment diminishes as it runs east to a much shallower slope 3 ft. tall with a gentle bench slope to the water (Figure 4). There is a rock outcrop at the easternmost point. The rest of the bench along the site is made up of stones, very small gravel, and clay.

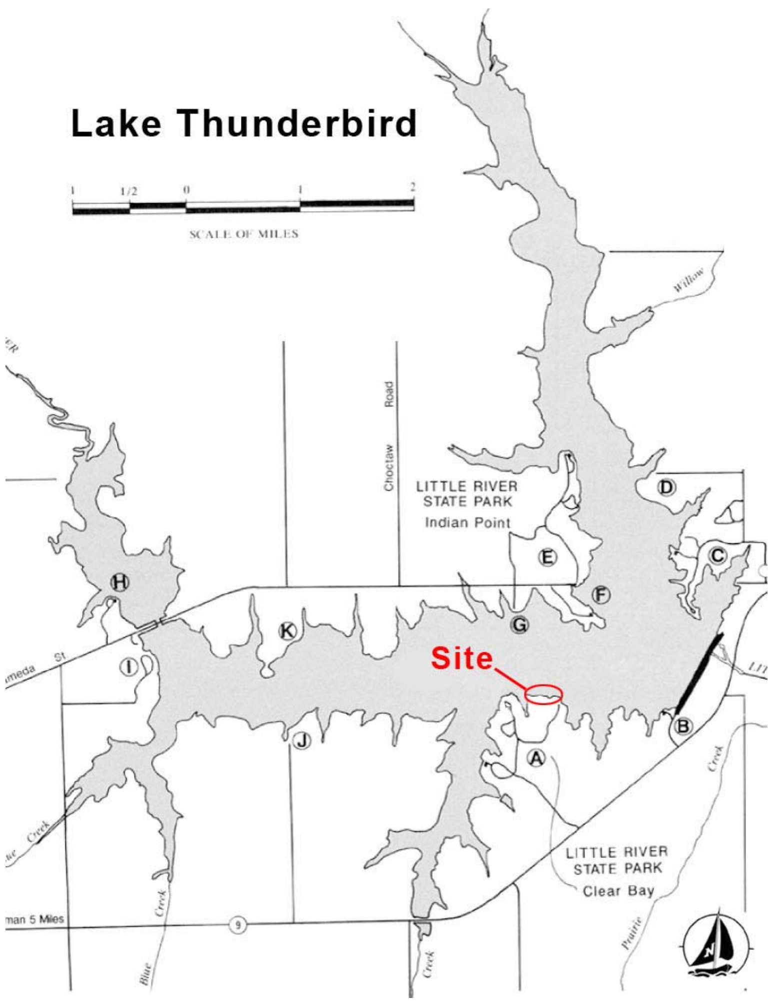


Figure 1: Map of Lake Thunderbird with Demonstration Site Indicated.

Figure 2: West end. Escarpment near Calypso Cove Marina. Note the once-buried telephone pole.

Figure 3: West end looking east. Eroded beach and drop-off at site. Note the once-buried telephone pole.

Figure 4: East end (Looking east). Gently sloping banks up to 3 ft. escarpment to the old roadbed.

TASK 2: IMPLEMENTATION OF BIOENGINEERING TECHNIQUES

Deliverables: Incorporated into the Final Report

Project Design

To accomplish the overall project objectives, the following goals were established for the site:

1. Install of wave deflection barriers (breakwaters) to provide protected calm waters for growing aquatic plants and allowing sediment to accumulate.

2. Establish stands of emergent aquatic plants behind the breakwater as a permanent system to dissipate wave energy and replace the project breakwaters as they decay.

3. Experiment with multiple types of breakwaters and plants to measure and demonstrate their effectiveness, complexity and suitability to the project.

In August of 2003, with the water level approximately 1.5 ft. down below the conservation pool of 1039’ (1,037.5’), 415 feet of breakwater were installed using 272’ of coir geotextile rolls (CGR) and 143’ of t-posts and wattle branchboxes (Figure 5, Figure 6, Figure 7). Branchboxes, which were taller, were installed where erosion was deemed most severe. Breakwater treatments were installed at the water line with the expectation that the normal pool would rise near the top of the coir rolls.

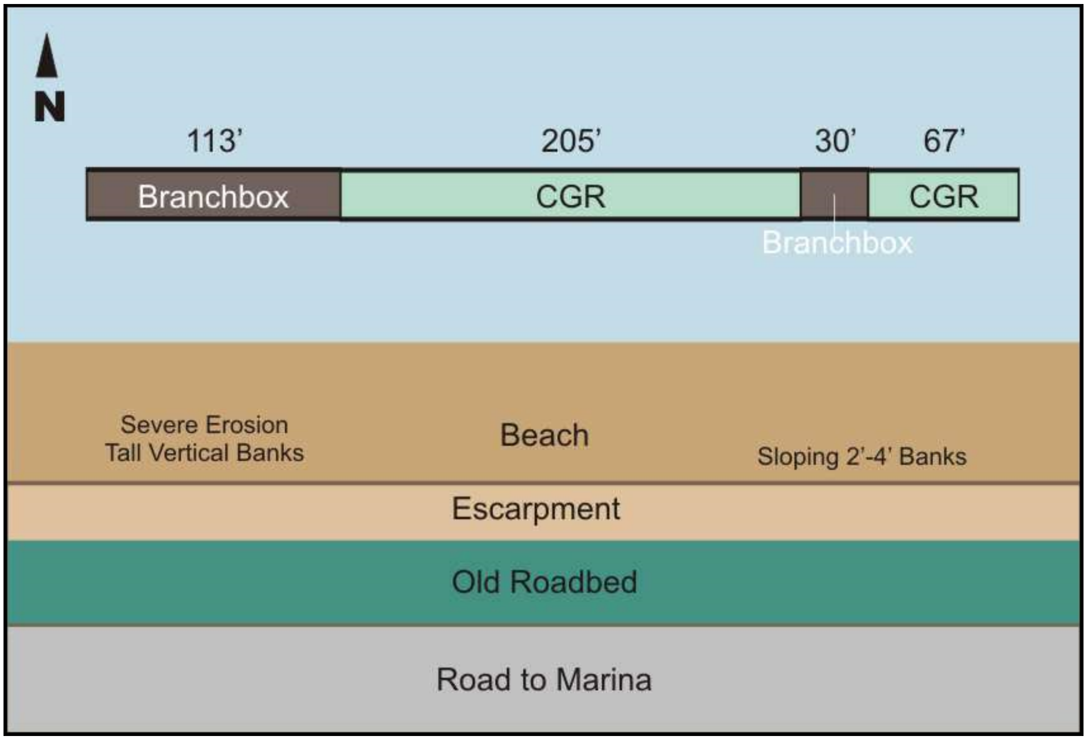


Figure 5: Breakwater Layout.

Figure 6: Branch box at west end - Zone 1.

Figure 7: CGR at east end - Zone 2.

Breakwater Construction

Branchbox breakwaters were constructed (Figure 8, Figure 9) from two facing t-posts driven into the substrate at one-meter intervals. Wired rolls of cut branches, or wattles, were placed between the fence posts, packed down and then wired to the posts (Figure 10). A final drive with a sledgehammer packed the posts and wattles together on the bottom. A rock toe was used to reinforce the breakwater and reduce scour (Figure 11). The breakwater was designed to protrude from the water slightly at conservation pool.

Figure 8: Posts and "Wattles" for branchbox breakwater.

Figure 9: Installing "wattles" (branch bundles) into branchbox.

Figure 10: Left – Driving t-posts. Right – Packing branch wattles.

Figure 11: Completed branchbox (1.5 ft. below conservation pool).

CGR breakwaters are more suitable for low-energy areas and their diameter limits them to 20" depths (Figure 12, Figure 13). CGRs are relatively expensive, approximately $13 / ft. but are much less labor intensive to install and will naturally disintegrate over time unlike the t-posts in the branchbox. The CGRs were held in place using baling wire tied to 2" x 4" x 24" wooden wedges. The CGRs are extremely heavy when wet as well and form a good barrier. They are also capable of collecting sediment and working as a direct media for vegetative expansion.

Figure 12: Staking a CGR.

Figure 13: CGRs installed.

Planting Installation

On September 1st through 5th of 2003, behind and parallel to the breakwater, a 30' to 40' strip of emergent aquatic vegetation was planted at and above the waterline (Figure 14). 500 plugs of assorted rushes, sedges and spikerush were supplied by Sanctuary Water Gardens of Blanchard, Oklahoma. In addition, the project purchased 175 softstem bulrush plugs and transplanted 500 plants from around the lake consisting primarily of common bulrush. Some sprigs of water willow and horsetail were intermixed with the transplanted bulrush. Several small willows and panicum grass were transplanted to mark transition areas from one zone to the other. For instance the panicum grass in the foreground of Figure 14 demarks the transition from primarily plug plantings (eastward) to lake transplants (westward).

Daytime high temperatures were above 100º F at the time of planting. The upper gravel and clay substrate was very dry. Subsequently the site was watered with an irrigation pump on two occasions soon after planting. Initially the plugs fared much better than the transplants most probably due to poor soil conditions.

Water levels were expected to rise as the summer turned to fall and the plants would be in saturated soil. Further, as the water entered in behind the protective breakwater sediment was to drop out and build up on the planted area creating a more hospitable substrate for the plants. Unfortunately the lake level did not reach conservation pool until almost a full year following breakwater completion. Consequently the plants did not have sufficiently saturated soils nor did the breakwaters have the opportunity to trap the finer silts and solids required to improve sediment structure.


Figure 14: Plugs after planting.

TASK 3: EROSION CONTROL MONITORING

Deliverables: Incorporated into the Final Report

Monitoring of site elevations and plants began immediately after the installation of breakwaters. A diagram of the site as constructed along with placement of monitoring transects and quadrats can be seen in Figure 15 below.

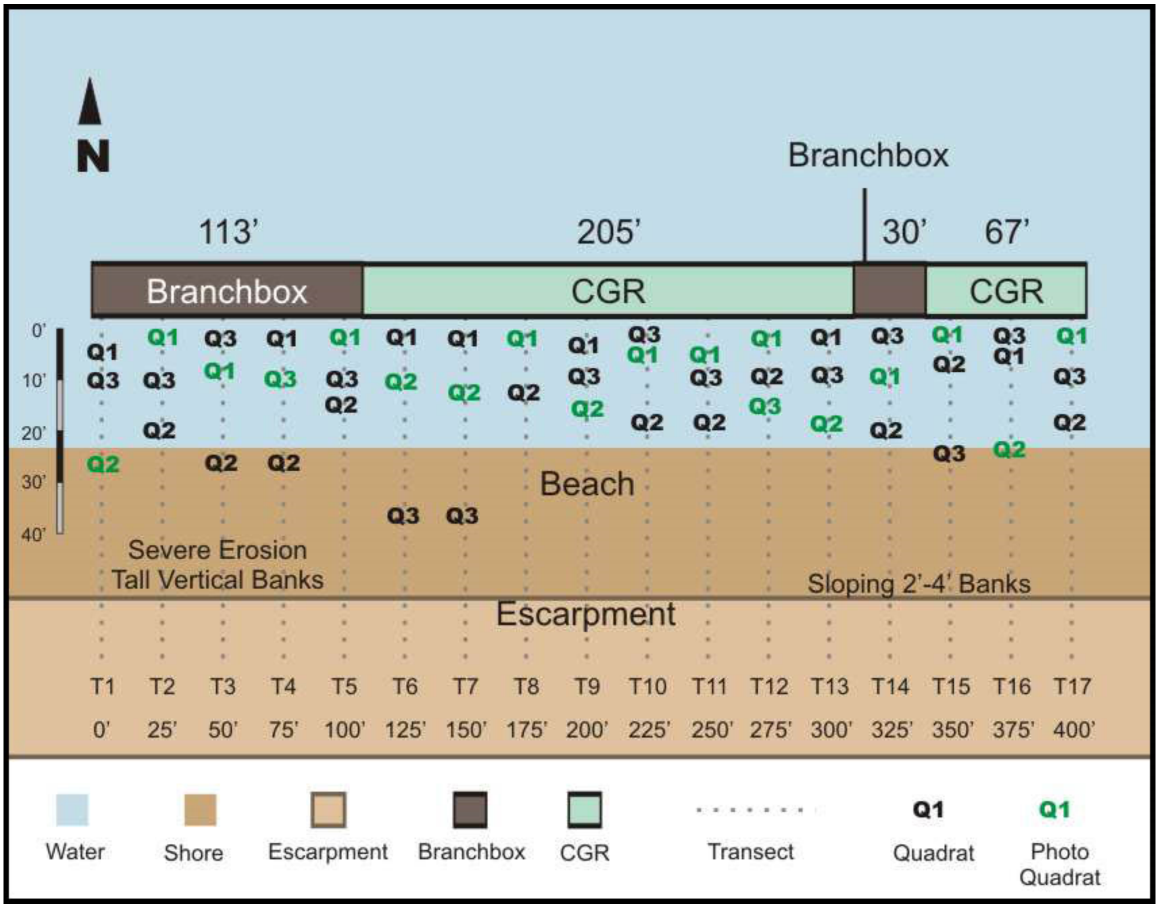


Figure 15: Site layout as constructed with monitoring transects and quadrats *(note: Q3's were moved from their original points on the escarpment down to the planting zones and are therefore out of sequence in some cases.)*

Elevation Survey Monitoring:

The initial layout for surveying the site was with assistance from 2 licensed surveyors of the Oklahoma Department of Transportation (ODOT) on August 26, 2003. A line was created roughly 50 feet upslope from and parallel to the breakwater. Flagged pins were placed every 25 feet along its course to establish the transects. ODOT trained the project manager on use of the transit, rod, note taking, setting permanent benchmarks, methods for calculating elevations, turning points, how to "close" the survey and calculation of percent error.
Per instruction from ODOT, for the elevation surveys, each transect was to have a measurement taken at each significant change in elevation. This varied from 5 to 18 readings per transect. Measurements were taken and recorded for the initial site elevations within the acceptable error limit.

The winter survey was missed due to changes in staff. The second survey, scheduled 6 months after the first, did not take place until the next summer, June 23, 2004. Prior to commencement of the second survey, Project Manager, Allyson Childress left the OWRB. Owen Mills took up her responsibilities on April 29th, 2004.

While processing data from the second survey it became apparent that the elevation data from the previous session was not usable. While elevation points had been taken, the distance between the points along any transect had not been recorded. Unfortunately, it is not possible to re-survey the points for comparisons between sessions. Consequently, no valid data collection occurred pre-implementation. Subsequent monitoring events ran a tape measure from the pin to the breakwater. New points were taken on the transects at every 5 feet beginning at the top of the escarpment and ending at the breakwater. This was deemed repeatable for subsequent sessions. Moreover, only 17 relevant transects were taken. Transects 18 and 19 were east and beyond the breakwater. Furthermore, they on were bare rock at the water so that neither sediment accretion nor plant growth would occur there.

The third survey session occurred on December 15, 2004 (1039.19' MSL). The fourth survey session occurred on March 30, 2005 (1039.29' MSL).

Summary of Elevation Survey events:

1.	8/26/03	Pre-Implementation Survey	Invalid
		Winter Survey Missed	
2.	6/23/04	Post-Implementation Survey 1	Valid
3.	12/15/04	Post-Implementation Survey 2	Valid
4.	3/30/05	Post-Implementation Survey 3	Valid

Elevation Survey Results:

Data from the survey sessions are presented in Appendix A.

Because the pre-implementation survey was not valid, only post-implementation data is available for evaluation. Results are derived by a comparison of the first and last comparable data sets approximately 9 months apart: 6/23/04 and 3/31/05. The expectation was for sediment accretion to be focused between the elevations of 1037' to 1041' behind the breakwater. This would be the toe of the bank to the breakwater. Elevation data began much higher at the top of the escarpment to capture periodic sloughing of the bank.

The overall average elevation change for the site was a loss of sediment of 0.11 ft. The effective site area would perhaps be more accurately represented by those measurements taken within the range of actual pool elevations normally from 1037' to 1039'. The average elevation change for those site measurements was a sediment loss of 0.13 ft. The average elevation change at points nearest the water's edge at the time of sampling (1039.26') was a loss of 0.24 ft. The average elevation change at points nearest the branchbox breakwaters was a loss of 0.04 ft.

The average change in elevation of points at the top of the bank was a loss of 0.15 ft and a maximum single point loss of 0.56 ft.

Avg Δ Elev (ft.)	**-0.11**
Avg Δ Elev (ft.) in-water only (~1037'-1038')	**-0.13**
Avg Δ Elev (ft.) at BW Elevation (~ 1037')	**-0.03**
Avg Δ Elev (ft.) behind Branchbox (~1037')	**-0.04**
Avg Δ Elev (ft.) at Water's Edge (~ 1038')	**-0.24**
Avg Δ Elev (ft.) at Top of Bank	**-0.15**

Table 1: Average Changes in Elevation

Plant Monitoring:

Plant Monitoring Data and Photographs are presented in Appendices B & C respectively.

Monitoring session #1 was done before planting on September 2, 2003 (1037.93' MSL). Measurements were accomplished using 3, 18" sample quadrants (Figure 16) per transect at a random distance from the breakwater to the pin. The same 25' survey transects were used. There were 19 transects of data recorded. On each transect one of the 3 quadrats was randomly chosen to be photographed. Also, there was a photograph taken looking east and west along 4 points of the demonstration site. All distances were measured along a transect using a 100' tape from a flagged point on the breakwater to the pin above the escarpment. The 18" x 18" quadrat was placed with its bottom right corner at the defined distance. It was placed in the water or on the ground and plants were counted by number of shoots or percent coverage if there were too many shoots.

Figure 16: 18"x18" Quadrat 1 Transect 5 from monitoring sessions 1 and 2.

Monitoring session 2 was performed on June 25, 2004 (1038.64' MSL). As in the survey sessions, only 17 of the original 19 transects were assessed. In addition, quadrat 3 was changed to a different distance for this and succeeding sessions because it was up on the escarpment and did not assess any of the planted work area. It was decided to keep quadrat 3 but move it to some place back in the planting zone of the project. To be consistent with the original randomness of quadrats 1 & 2, all third quadrants were chosen to be at either 2, 10, or 15 feet from the breakwater, dependent on what breakwater distance quadrats 1 and 2 were at on the transect at hand. To avoid having two quadrats very close together, the distance chosen, 2, 10, or 15 feet was the one that would be furthest from quadrat 1 or 2.

Monitoring session 3 was performed on December 8, 2004 (1039.72' MSL). Monitoring session 4 was performed on July 15, 2005 (1038.57' MSL).

Summary of Plant Monitoring events:

1.	9/2/03	Pre-Implementation Survey	Valid
		Winter survey missed	
2.	6/25/04	Post-Implementation Survey 1	Valid
3.	12/08/04	Post-Implementation Survey 2	Valid
4.	7/15/05	Post-Implementation Survey 3	Valid

Plant Monitoring Results:

Final counts of the sample quadrats produced 55 shoots of 5 species: Softstem bulrush (Schoenoplectus tabernaemontani), common bulrush (Schoenoplectus americanus), water willow (Justicia americana), sedge (Carex spp.) and pondweed (Potamogeton spp.). The average density of shoots per square foot is 0.48. The average density just behind the remaining breakwaters (see Problems Encountered below) was 1.57 shoots per square foot.

Final plant counts can be found in Tables 2, 3 and 4:

Plant Counts Extrapolated on the Entire Site (area = 12,110 sqft - 415' x 29')	
Total No. Shoots (w/in 51 quadrats**)**	**55**
Density of Shoots w/in entire Study Area (shoots/sqft)	**0.48**

Table 2: Plant Counts - Totals and Densities of the Entire Site

Plant Counts Extrapolated Behind Remaining Breakwaters (area = 4,057 sqft - 143' x 28')	
Total No. Shoots (15 quadrats)	**53**
Density of. Shoots Transects 1-5 & Transect 14 (shoots/sqft)	**1.57**

Table 3: Plant Counts - Totals and Densities Behind the Breakwater

Final No. Of Shoots per Species w/in Sample Quadrats				
	Pre - Implementation	Post-Implementation		
	Fall '03	Summer '04	Winter '04	Summer '05
WW	15	6	1	21
Bulrush	0	7	8	28
Horsetail	0	0	1	0
Juncus	0	2	0	0
Chara	0	0	0	38 + 10% of one quadrat
Sedge	0	0	0	2
Potamogeton	7	0	0	4 + 70% of one quadrat

Table 4: No. of Shoots per Species w/in Sample Quadrats

Discussion of Plant Survey Results:

September 2, 2003: The preliminary sampling of extant plants before planting showed a prevalence of terrestrial species with a few scattered water willows (*Justicia americana*) and pondweed (*Potamogeton spp*.), at or above the 1040' pool elevation. No other aquatic species were found (Figure 17).

June 25, 2004: In the second session there was reasonable survival given the drought conditions the plants had experienced. Although numerous species were planted, the survivors noted this session were water willow, softstem and common bulrush.

December 8, 2004: The water was still warm and the lake had not yet experienced its first freeze. It is not presumed that the December assessment date had a great effect on the survival counts for bulrush or water willow. The limited species that were seen in the previous session were still vibrant and not yet dormant (Figure 18).

July 15, 2005: By the final session, most survival was seen behind the remaining breakwaters. Virtually no emergent species remained in areas no longer protected by the CGR breakwater. Bulrush behind the larger west branchbox was healthy and vegetatively reproducing in dense stands. The branchboxes also appear to have provided enough protection to assist in volunteer aquatic vegetation to crop up, specifically Chara and a filiform species of Potamogeton.

Figure 17: Sparse vegetation on original shore

Figure 18: Tall healthy stand of softstem bulrush. View of western branchbox, December 8, 2004.

TASK 4: REPORTING

Deliverables: Progress Reports and Final Reports

Quality Assurance Project Plan was sent to EPA for approval December 16, 2002. Semiannual Progress Reports were submitted as required. This Final Report is due August 1, 2005.

PROBLEMS ENCOUNTERED AND SOLUTIONS:

Problem 1. The Coir breakwater (CGR) washed out after a storm in July of 2004 after waters had finally risen to the top of the CGRs. Heavy waves apparently rocked the CGRs enough to rub the outer netting against the baling wire that held them in place. This rubbing action worked to eventually sever the netting on the CGRs and loose the fibers within. Only three rolls remained when the problem was discovered on July 8th, 2004. From these rolls it was possible to see the cut nets and determine what happened to the collapsed rolls (Figure 19). Many of the wooden stakes had pulled up or come loose as well. The coconut husk fibers collected along the shore (Figure 20).

Solution: While nothing could be done to repair the disintegrated CGRs, remedies can be formulated for use of such rolls as breakwaters in future projects.

Heavier vinyl coated 3/16” cable should be substituted for the thin baling wire to protect the netting from abrasion. More durable nylon netting is available for CGRs and should probably be used in future projects. The netting for these CGRs was a natural fiber rope chosen because it would biodegrade over time. Another anchoring system should be used for the CGRs instead of the 24” wooden stakes to insure they stay in place.

Figure 19: Wave action and baling wire severs netting on a remaining CGR that will eventually allow fibers to wash out.

Figure 20: July 14, 2004 - Assessment of CGR breakwater collapse after storm event. Coconut fiber rests on the shore with remaining plants once protected by the CGR.

Problem 2. Branchbox breakwaters are laborious. While they were very effective at dampening the waves and protecting the plants behind them, they were difficult to build.

Solution: For future projects, branchbox breakwaters should be used in short expanses where there is severe erosion such as can be seen at this demonstration site. Low to the ground, easily accessible branches should be readily available. Soft substrate is also important to facilitate driving the substantial number of t-posts required for such a breakwater.

Problem 3. Difficult to accurately assess plant species and densities; quadrat sampling at low plant density (due to low initial survival) may not have given the best representative data.

Solution: Future projects should map out a planting plan with predetermined plant locations and densities. Plants might be grouped by species and possibly across contours to test what levels work best for each species. Documentation of actual plantings should be compared against the plan. Comparisons could more easily be made between sessions. For a project such as this, simple photo documentation of each transect is probably sufficient to describe survival and success. Some written estimate of percent species mix could augment each photo.

Problem 4. Plant survival overall was poor.

Solution: In future projects several plantings during different months over 2 to 3 growing seasons should be scheduled. This allows for the very real possibility of drought, high water levels, herbivory, and so forth that may occur during any one season. Multiple aggressive species should be planted over a wider elevation range. Breakwaters should be established at a lower elevation to allow protection of some submersed species as well. Water willow and bulrush should be considered for erosion control of most lakes in Oklahoma because they are so drought hardy, are resistant to herbivory, rapidly spread and offer superior shoreline protection when established. In cases where the existing sediment is poor, establish the breakwater several months prior to planting. This may allow for accretion of finer silts and organics as sediment behind the breakwater creating an environment beneficial to aquatic plants.

Problem 5. Lake level did not come up as expected to wash over the breakwaters and trap the suspended solids needed for shoreline accretion and plant survival.

Solution: Consider using some type of floating breakwater to establish breakwaters and plants lower in the lake. This method would give a wider range of possible elevations that may occur in any given year(s) due to climatic fluctuations.

Problem 6. Elevation measurements using a stadia rod opened the likelihood for small changes in rod placement and therefore changes in data points.

Solution: Given the small changes the project was looking for, a more precise method would be to use permanent stakes or t-posts and take subsequent measurements from the top of the post down to the sediment. This method would be more accurate and save time.

MEASURES OF SUCCESS:

The Measure of Success as defined in the Project QAPP is as follows:

"A7.5. Decision Rule

Decisions to be made will be based on first and second year data from the demonstration. Plant establishment is typically a four or five year process. Basing treatment success on one or two years of data would increase the likelihood of decision errors being made. This requires us to take a more broad view of the decision rule. There are, however, scenarios that would strongly suggest success or failure. For the latter these include catastrophic failure of the breakwater, negative accumulation (sediment loss) or total plant loss due to herbivory or other disturbance. Success may be indicated by substantial sediment accumulation in the first year, visual confirmation of plant cover or an explosive plant reproductive rate in the quadrats. Coexisting between the two extremes are potential situations that are too close to call. For this reason we have crafted a decision rule that will not promote choosing one of the two extremes prematurely:

If the breakwater and other controls are intact and functioning as intended (with a positive accumulation of sediment) and plants are showing positive growth trends, treatment will be considered successful at that time and recommended for future observation."

Breakwaters:

The branchbox breakwater performed well in slowing wave action and protecting the plants behind it. It is behind the branchbox breakwaters where dramatic vegetation is spreading. This is evidenced by the stark disproportion of plants behind the western branchbox and those left unprotected in the now open CGR areas.

The eastern branchbox was 30' in length, which is not long enough to afford full protection from indirect wave action entering from the sides. The branchbox did however protect several bulrush plants that may fully populate the zone immediately behind it. This breakwater is approximately 1 foot deeper than the western branchbox and is overtopped by the current water levels. The harsh environment is evident by lower survival predicting that and vegetation will be slow to spread.

To be successful the CGR breakwater must remain intact for at least two growing seasons for plants to establish behind it.

Shoreline accretion:

The goal of positive shoreline accretion was unsuccessful due to the loss of a majority of the breakwater. There is visible evidence that accretion did occur as the rocky substrate silted in behind the shorter branchbox breakwaters but was immeasurable overall. Average shoreline accretion for all points over the entire site was a negative 0.11 feet. When considering strictly the shoreline behind the remaining branchbox breakwaters, accretion/erosion is negligible (See Table 1). The most notable changes occurred at the water's edge near 1038' (excluding those transects protected by the branchboxes) showing almost one-quarter foot loss.

The average change in elevation of points at the top of the bank was a loss of 0.15 ft and a maximum single point loss of 0.56 ft. These measurements show considerable upland erosion. This site and others like it could have terrestrial woody species put in place to decrease this loss. Bundled willow cuttings could be affixed along this entire escarpment. Also, a healthy stand of aquatic plants, such as bulrush, would act well as a buffer to accumulate and keep much of that erosion from entering the lake.

While below the detection of our chosen methods, positive accretion was visible and did occur just shoreward of the breakwaters (near 1,037' MSL) where very shallow water (several inches) pooled behind (Figure 21 & Figure 22). Fine sediment settled and filled in between the small rocks that originally made up the shore.

Figure 21: Rocky shoreline at time of breakwater installation, August 2003.

Figure 22: Fine Sediment filled in the originally rocky shore, April 2004.

Survival and growth of planted vegetation:

Plant survival and growth can be deemed successful in part given that there is a "*visual confirmation of plant cover and explosive plant reproductive rate*" behind the breakwaters. Plant assessments calculate an overall increased density (after planting) of 480% with the vast majority of those plants growing behind the remaining of breakwater, approximately one-third of the site. This can be further illustrated negatively by comparing planted sites where the CGR breakwater collapsed. Figure 23 shows quadrat T17Q1 with one year of significant plant growth behind the CGR and the complete absence of any plants in the subsequent year following the CGR collapse.

Figure 23: T17Q1 Before (6/23/04) and After (7/15/05) CGR collapse

The final plant counts and densities for the entire site and for the area behind the remaining breakwaters are shown in Table 2 & Table 3. While site-wide survival was poor the remaining plants protected behind the extant breakwater are vigorous and expanding exponentially (Figure 24). There were approximately 1,175 assorted macrophyte plugs and sprigs planted at a density of 0.1 plants per sqft. The calculated density by project end for the site was 0.48 plants per sqft.; an increased density of 480%. The final estimated number of shoots behind the breakwaters is over 6,300; a density of 1.5 shoots per sqft. (primarily bulrush and waterwillow); an increased density of 1,500%.

Before lake levels came up, the bulrush was small and mainly grew close to the breakwater within the saturated sediment (Figure 25). There were few shoots and very little vegetative reproduction. Once lake levels returned to the conservation pool elevation (near 1,039') the still-protected bulrush spread exponentially behind the breakwater (Figure 24). This is evidence of the demonstration's real potential when water and a firm breakwater are present. The vigorous growth indicates the potential for initial low plant density to effect a long-term change in physical structure. Barring other disaster or herbivory, the worst of this site will eventually be covered by bulrush, both *americanus* and *tabernaemontani*.

Figure 24: Softstem bulrush stand looking west, July 2005, grows towards the shoreline.

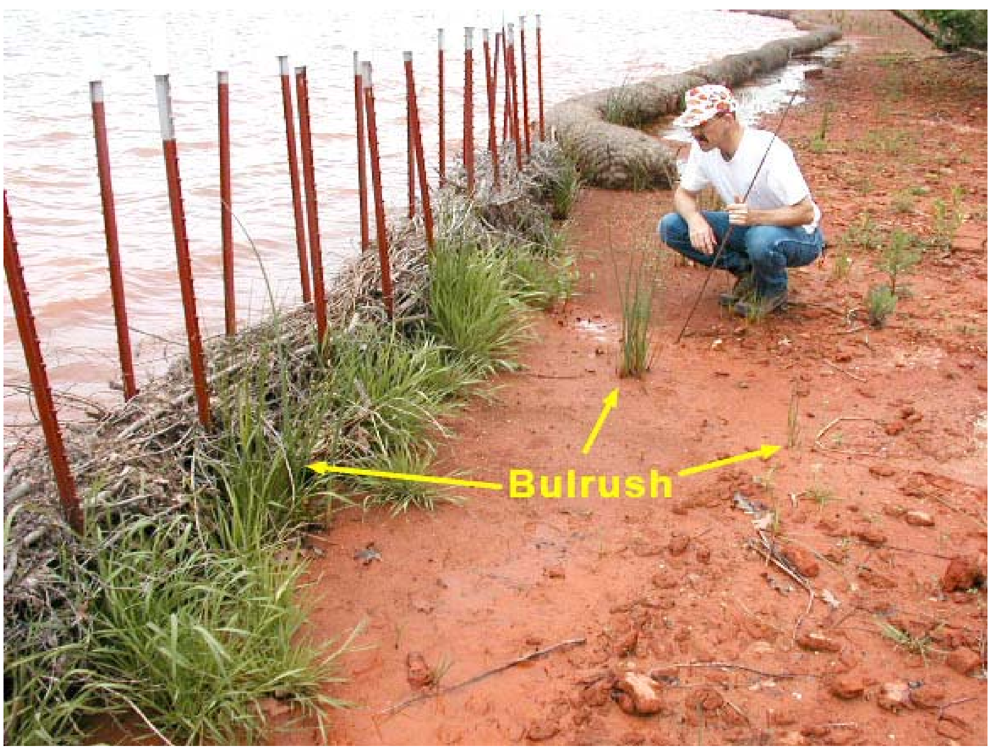


Figure 25: The same softstem bulrush stand looking east, April 2004 8 months after planting and before lake levels rose.

The potential for this site to establish a dense stand of emergent aquatic macrophytes has been shown in this demonstration. That potential can be expressed as a function of time and water levels combined with the presence of a working breakwater as shown in Figure 26. This graph shows a calculated increased plant population of 360% over the first year even though water levels were well under the 1,039' conservation pool level. This supports that aquatic plants can do well on the site even under harsh relatively dry conditions. In the following year, with only one-third of the site area still protected by the breakwater, counts still showed a 137% increase in overall shoot population once the water levels rose above 1,039' and saturated the plants. The plants counted were almost entirely behind the branchbox breakwaters. Extrapolating the number of plants calculated* behind the remaining branchboxes over the entire site would give a 450% increase for the year. This extrapolation can only be used as an indicator that there is potential to rapidly populate this site with water willow, softstem bulrush and common bulrush given a steady breakwater and enough growing seasons to allow for water level fluctuations.

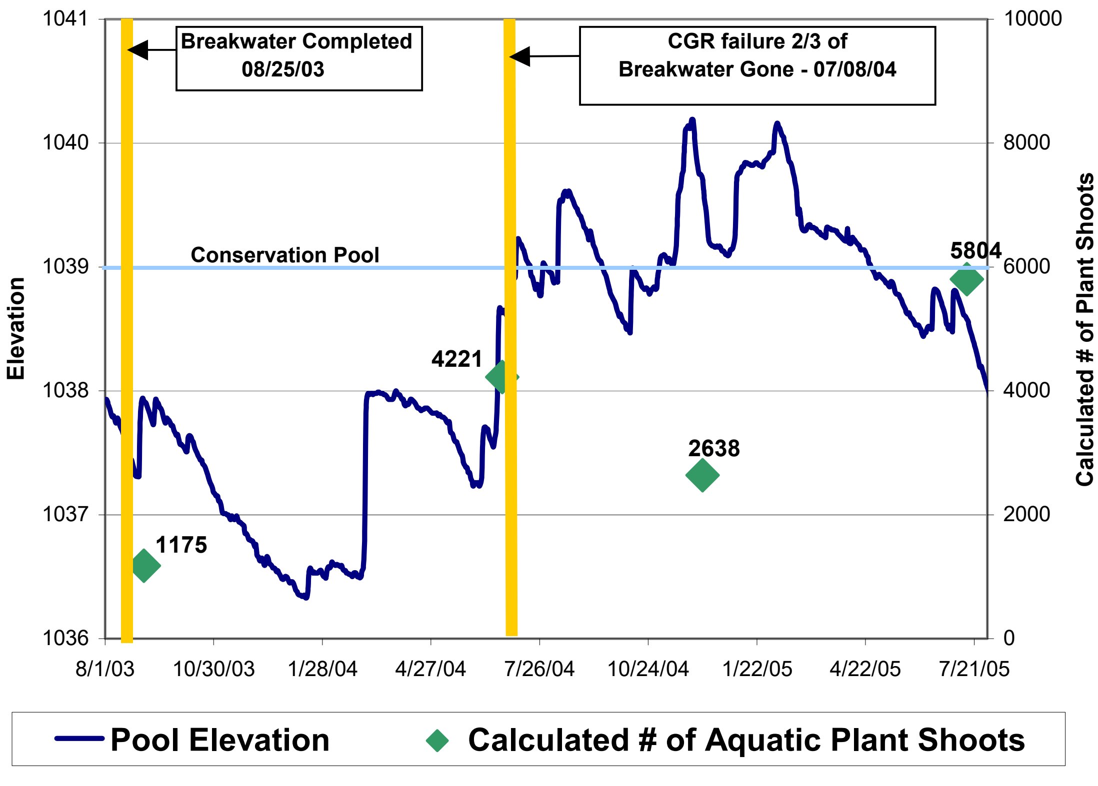


Figure 26: Graph - Plant counts and pool elevations

*Plants behind the branchbox are calculated as 53 Shoots / 15 quadrats / 2.25 sqft. per quadrat x 12,110 sqft. for the site or 19,017 shoots site-wide.

SUMMARY:

Bio-engineering methods for erosion control in Lake Thunderbird are a viable option for lake managers. The virtual explosion of plant expansion behind the western breakwater, the only breakwater affording the full protection that was intended, demonstrates that aquatic macrophytes can be established even in a poor quality gravel substrate. Continued observation will be necessary to confirm that these plants will continue to fill in the shoreline, and as the branchbox gives way, survive the wave action, dissipate wave energy to the site, protect the escarpment, and capture upland eroded sediment.

For the future of the demonstration site, it is evident that a portion, roughly 30% of the 400’ shoreline, will be afforded some protection in the long-term from wave erosion due to the establishment of the softstem and common bulrush and waterwillow found behind the still existent branchbox breakwaters. These plants will also act as a sediment trap for upland erosion as well and help to level out the now vertical escarpment that overshadows the site today. Without a contiguous breakwater, growth out from behind the branchboxes will be slow but should occur over time. Barring herbivory, further severe drought or other adversity the shoreline protection will develop from natural spread of this established stand of bulrush. Protection immediately adjacent to the demonstration site is not likely as it is bounded by hard rock substrate on either side. Natural reproduction may spread via seeds however to other protected areas of the lake.

Branchboxes and CGRs can work as breakwaters but other methods that are easier to employ and/or less expensive should also be attempted at Lake Thunderbird. A floating breakwater that can be deployed in deeper water, which would allow for a wider range of planting elevations and species, should be considered, e.g. cedar tree breakwater, floating culverts and so forth.

The problems encountered within the project have strengthened its sister §319 project at Lake Carl Blackwell near Stillwater, Oklahoma. Lake Carl Blackwell will greatly benefit from the lessons learned in this Lake Thunderbird project. All of the solutions that have been delineated in the Problems Encountered and Solutions section of this report will be implemented where applicable.

Timeline of Events:

Date	Event / Comment	Pool Elevation
8/25/03	Installation of Breakwaters this week	1037.36
8/26/03	Elevation Survey 1 – Invalid data – Horizontal distance between intervals on transects were not recorded	1037.32
9/2/03	Plant Monitoring 1 before planting – sparse water willow found	1037.93
9/2-5/03	Planted Site this week ~1,175 propagules	1037.92
	Pool elevation continues to drop and does not come up to breakwaters until June 2004.	
Early '04	Missed monitoring interval – 2/26/04 Project manager resigns	
4/29/04	New Project Manager is hired	
6/22/04	First time CGR's are submersed since installation	**1038.60**
6/23/04	Elevation Survey 2 – 10-month interval between surveys due to Staff change. First usable data taken – New survey points are used at 5' intervals since original intervals were not recorded	1038.65
6/25/04	Plant Monitoring 2 - 10-month interval between surveys due to Staff change	1038.64
6/28/04 to 7/7/04	7 storm events in 9 days totaling 2.42" with max. wind gusts from 16-44 mph.	
7/8/04	Remains of CGR's are discovered on shore 18 days after CGR's are submersed	**1039.19**
12/8/04	Plant Monitoring 3 – Exponential vegetative reproduction of bulrush found behind remaining breakwaters	1039.72
12/15/04	Elevation Survey 3	1039.29
3/30/05	Elevation Survey 4 conducted for Final Report due 4/15. Overall sediment accretion was -0.11 ft. Overall change behind remaining breakwaters was negligible.	1039.29
4/8/05	Extension to 8/1/05 for Final Report requested – Plant counts were deemed premature for final report. Final assessment would await summer growth.	
7/15/05	Plant Monitoring 4 – Considerable growth and expansion of bulrush and water willow behind remaining breakwaters. Original planted density for the Site was 0.1 plants / sqft. Final density was 0.5 plants / sqft. for the Site or 1.6 plants / sqft. behind the breakwaters.	1038.58

Table 5: Summary: Timeline of Events

Conclusions:

- Softstem bulrush, common bulrush and waterwillow are excellent species for erosion control at Lake Thunderbird due to their prolific spread in protected areas, drought hardiness, and resistance to herbivory.
- Breakwaters need to encompass more than 30% of the site's shoreline to trap sediment effectively.
- Breakwaters are effective in establishing aquatic plants for shoreline erosion control.
- Breakwaters must effectively protect aquatic macrophytes for at least two years, and probably more, to allow long-term establishment of macrophytes dense enough to protect and populate the shoreline.
- Projects should expect that several plantings will be required over at least 2 and probably 3 seasons to establish aquatic vegetation. This is because it is unlikely that climatic conditions will cooperate in the course any one planting.
- A wide range of elevations should be planted in future projects to account for drought and fluctuating water levels. The best strategy would be multiple plantings of various species both submersed and emergent ranging in elevation from the highest monthly average pool elevation to the lowest monthly average elevation.
- CGR rolls must be extremely well anchored and their netting must be protected from abrasion by anchor cables because they act as a virtual wall in the water, unlike other breakwaters that may simply diminish the waves.
- Branchbox breakwaters are excellent breakwaters. They greatly reduce wave action and sufficiently calm the waters shoreward to allow for deposition of sediment. They are very sturdy and should last long enough to get plants well established.
- Branchbox breakwaters are labor intensive and may be inappropriate for long stretches of shoreline. They might be more effectively used in short reaches that have extensive erosion and need effective protection.
- Other methodologies for fast, effective, yet inexpensive breakwaters should be researched and attempted in future demonstrations.
- Softstem bulrush (Schoenoplectus tabernaemontani), common bulrush (*Schoenoplectus americanus*) and water willow (*Justicia americana*) are excellent candidates for erosion control in Lake Thunderbird and should be considered for other Oklahoma lakes. They have proved to be fast colonizers and resistant to herbivory along similar exposed shorelines.

APPENDIX A

Elevation Survey Data

First Usable* Elevation Survey
6-26-04

Transect	H.I.	F/S	ELEV (ft)	Distance from Pin (feet)	
06/23/2004					
1	103.39	5.65	97.74	0	Top of Escarpment
1	103.39	9.39	94	10	Toe of Escarpment
1	103.39	10.16	93.23	15	
1	103.39	10.72	92.67	20	
1	103.39	11.35	92.04	25	
1	103.39	11.66	91.73	30	
1	103.39	11.91	91.48	35	
1	103.39	12.2	91.19	40	
1	103.39	12.27	91.12	42	Breakwater
2	103.39	5.6	97.79	5	Top of Escarpment
2	103.39	8.49	94.9	10	Toe of Escarpment
2	103.39	9.53	93.86	15	
2	103.39	10.32	93.07	20	
2	103.39	11.09	92.3	25	
2	103.39	11.67	91.72	30	
2	103.39	12.01	91.38	35	
2	103.39	12.26	91.13	40	
2	103.39	12.32	91.07	43.3	Breakwater
3	103.39	5.83	97.56	8	Top of Escarpment
3	103.39	9.85	93.54	20	Toe of Escarpment
3	103.39	10.43	92.96	25	
3	103.39	11.32	92.07	30	
3	103.39	11.77	91.62	35	
3	103.39	12.02	91.37	40	
3	103.39	12.12	91.27	45	Breakwater
4	103.39	4.83	98.56	24.5	Top of Escarpment
4	103.39	11.04	92.35	31	Toe of Escarpment
4	103.39	11.49	91.9	35	
4	103.39	11.96	91.43	40	
4	103.39	12.22	91.17	45	
4	103.39	12.34	91.05	48.9	Breakwater
5	103.39	4.4	98.99	23.4	Top of Escarpment
5	103.39	10.66	92.73	30	Toe of Escarpment
5	103.39	11.58	91.81	35	
5	103.39	11.88	91.51	40	
5	103.39	12.23	91.16	45	
5	103.39	12.32	91.07	50.2	Breakwater
6	103.39	5	98.39	27.6	Top of Escarpment
6	103.39	11.01	92.38	32	Toe of Escarpment
6	103.39	12.04	91.35	40	
6	103.39	12.33	91.06	45	
6	103.39	12.52	90.87	50	
6	103.39	12.59	90.8	51.6	Breakwater
7	104.34	6.6	97.74	29	Top of Escarpment
7	104.34	12.15	92.19	33	Toe of Escarpment
7	104.34	13	91.34	40	
7	104.34	13.38	90.96	45	
7	104.34	15.53	88.81	49.5	Breakwater
8	104.34	4.55	99.79	14	Top of Escarpment
8	104.34	11.46	92.88	26	Toe of Escarpment
8	104.34	12.27	92.07	30	
8	104.34	12.81	91.53	35	
8	104.34	13.18	91.16	40	
8	104.34	13.48	90.86	45	
8	104.34	13.56	90.78	47.2	Breakwater
9	104.34	4.91	99.43	14	Top of Escarpment
9	104.34	11.52	92.82	24	Toe of Escarpment
9	104.34	12.36	91.98	30	
9	104.34	13.06	91.28	35	
9	104.34	13.33	91.01	40	
9	104.34	13.52	90.82	45	Breakwater
10	104.34	4.8	99.54	11	Top of Escarpment
10	104.34	9.94	94.4	16	Toe of Escarpment
10	104.34	10.81	93.53	20	
10	104.34	11.46	92.88	25	
10	104.34	12.17	92.17	30	
10	104.34	12.74	91.6	35	
10	104.34	13	91.34	40	
10	104.34	13.16	91.18	44	Breakwater
11	104.34	4.89	99.45	7.9	Top of Escarpment
11	104.34	10.48	93.86	16	Toe of Escarpment
11	104.34	11.18	93.16	20	
11	104.34	11.52	92.82	25	
11	104.34	12.06	92.28	30	
11	104.34	12.68	91.66	35	
11	104.34	13.13	91.21	40	
11	104.34	13.35	90.99	45	
11	104.34	13.43	90.91	46.7	Breakwater
12	104.34	5.69	98.65	16	Top of Escarpment
12	104.34	10.53	93.81	20	Toe of Escarpment
12	104.34	11.16	93.18	25	
12	104.34	11.72	92.62	30	
12	104.34	12.34	92	35	
12	104.34	12.95	91.39	40	
12	104.34	13.44	90.9	45	
12	104.34	13.6	90.74	47.9	Breakwater
13	104.34	5.1	99.24	12	Top of Escarpment
13	104.34	10.05	94.29	21	Toe of Escarpment
13	104.34	10.76	93.58	25	
13	104.34	11.44	92.9	30	
13	104.34	11.96	92.38	35	
13	104.34	12.53	91.81	40	
13	104.34	13.12	91.22	45	
13	104.34	13.46	90.88	49	Breakwater
14	105.88	6.16	99.72	9.4	Top of Escarpment
14	105.88	10.04	95.84	15	Toe of Escarpment
14	105.88	11	94.88	20	
14	105.88	11.55	94.33	25	
14	105.88	12.26	93.62	30	
14	105.88	12.85	93.03	35	
14	105.88	13.49	92.39	40	
14	105.88	14.18	91.7	45	
14	105.88	14.61	91.27	50	
14	105.88	15.01	90.87	53.5	Breakwater
15	105.88	5.9	99.98	7.75	Top of Escarpment
15	105.88	9.24	96.64	13	Toe of Escarpment
15	105.88	9.53	96.35	15	
15	105.88	10.1	95.78	20	
15	105.88	10.75	95.13	25	
15	105.88	11.15	94.73	30	
15	105.88	12.23	93.65	35	
15	105.88	12.81	93.07	40	
15	105.88	13.35	92.53	45	
15	105.88	14.02	91.86	50	
15	105.88	14.64	91.24	55	
15	105.88	14.9	90.98	58	Breakwater
16	105.88	6.77	99.11	20	Top of Escarpment
16	105.88	8.97	96.91	22.5	Toe of Escarpment
16	105.88	9.46	96.42	25	
16	105.88	10.19	95.69	30	
16	105.88	10.75	95.13	35	
16	105.88	11.45	94.43	40	
16	105.88	12.18	93.7	45	
16	105.88	12.64	93.24	50	
16	105.88	13.34	92.54	55	
16	105.88	14.09	91.79	60	
16	105.88	14.45	91.43	65	
16	105.88	14.55	91.33	66.9	Breakwater
17	106.48	8.36	98.12	34	Top of Escarpment
17	106.48	10.74	95.74	36	Toe of Escarpment
17	106.48	12.68	93.8	50	
17	106.48	13.4	93.08	55	
17	106.48	14.02	92.46	60	
17	106.48	14.91	91.57	65	
17	106.48	15.32	91.16	70	
17	106.48	15.35	91.13	71.2	Breakwater
18	106.48	10.12	96.36	54	Top of Escarpment
18	106.48	12.58	93.9	57	Toe of Escarpment
18	106.48	13.1	93.38	60	
18	106.48	13.61	92.87	65	
18	106.48	14.43	92.05	70	
18	106.48	14.71	91.77	73	Water's Edge - Rock

*** First Survey done on 8-26-03 did not yeild usable data because distances between transect points were not recorded**

Second Elevation Survey
12-15-04

Transect	H.I.	F/S	ELEV (ft)	Distance from Pin (feet)	
12/15/2004					
1	107.45	9.7	97.75	0	Top of Escarpment
1	107.45	13.46	93.99	10	Toe of Escarpment
1	107.45	14.18	93.27	15	
1	107.45	14.74	92.71	20	
1	107.45	15.41	92.04	25	
1	107.45	15.73	91.72	30	**Water's Edge begins**
1	107.45	16.02	91.43	35	In Water
1	107.45	16.2	91.25	40	In Water
1	107.45	16.32	91.13	42	**Breakwater**
2	107.45	9.55	97.9	5	Top of Escarpment
2	107.45	12.5	94.95	10	Toe of Escarpment
2	107.45	13.55	93.9	15	
2	107.45	14.34	93.11	20	
2	107.45	15.16	92.29	25	
2	107.45	15.74	91.71	30	**Water's Edge**
2	107.45	16.06	91.39	35	
2	107.45	16.24	91.21	40	
2	107.45	16.33	91.12	43.3	**Breakwater**
3	107.45	9.96	97.49	8	Top of Escarpment
3	107.45	13.81	93.64	20	Toe of Escarpment
3	107.45	14.46	92.99	25	
3	107.45	15.38	92.07	30	**Water's Edge**
3	107.45	15.82	91.63	35	
3	107.45	16.09	91.36	40	
3	107.45	16.22	91.23	45	**Breakwater**
4	107.45	8.66	98.79	24.5	Top of Escarpment
4	107.45	15	92.45	31	Toe of Escarpment
4	107.45	15.66	91.79	35	**Water's Edge**
4	107.45	15.98	91.47	40	
4	107.45	16.28	91.17	45	
4	107.45	16.45	91	48.9	**Breakwater**
5	107.45	11.37	96.08	23.4	Top of Escarpment
5	107.45	15.02	92.43	30	Toe of Escarpment
5	107.45	15.64	91.81	35	**Water's Edge**
5	107.45	15.99	91.46	40	
5	107.45	16.2	91.25	45	
5	107.45	16.52	90.93	50.2	**Breakwater**
6	104.32	6.5	97.82	27.6	Top of Escarpment
6	104.32	12.2	92.12	32	Toe of Escarpment
6	104.32	13.06	91.26	40	
6	104.32	13.33	90.99	45	
6	104.32	13.62	90.7	50	
6	104.32	13.76	90.56	51.6	**Breakwater**
7	104.32	6.85	97.47	29	Top of Escarpment
7	104.32	12.39	91.93	33	Toe of Escarpment
7	104.32	13.02	91.3	40	
7	104.32	13.39	90.93	45	
7	104.32	13.6	90.72	49.5	**Breakwater**
8	104.32	4.52	99.8	14	Top of Escarpment
8	104.32	11.28	93.04	26	Toe of Escarpment
8	104.32	12.21	92.11	30	**Water's Edge**
8	104.32	12.82	91.5	35	
8	104.32	13.2	91.12	40	
8	104.32	13.48	90.84	45	
8	104.32	13.74	90.58	47.2	**Breakwater**
9	104.32	4.76	99.56	14	Top of Escarpment
9	104.32	11.98	92.34	24	Toe of Escarpment
9	104.32	12.6	91.72	30	**Water's Edge**
9	104.32	12.99	91.33	35	
9	104.32	13.3	91.02	40	
9	104.32	13.6	90.72	45	**Breakwater**
10	104.32	4.9	99.42	11	Top of Escarpment
10	104.32	10.96	93.36	16	Toe of Escarpment
10	104.32	11.3	93.02	20	
10	104.32	11.92	92.4	25	
10	104.32	12.59	91.73	30	**Water's Edge**
10	104.32	12.92	91.4	35	
10	104.32	13.22	91.1	40	
10	104.32	13.34	90.98	44	**Breakwater**

Transect	H.I.	F/S	ELEV (ft)	Distance from Pin (feet)	
12/15/2004					
11	104.63	5.13	99.5	7.9	Top of Escarpment
11	104.63	10.58	94.05	16	Toe of Escarpment
11	104.63	10.95	93.68	20	
11	104.63	11.58	93.05	25	
11	104.63	12.43	92.2	30	**Water's Edge**
11	104.63	12.96	91.67	35	
11	104.63	13.31	91.32	40	
11	104.63	13.6	91.03	45	
11	104.63	13.71	90.92	46.7	Breakwater
12	104.63	5.91	98.72	16	Top of Escarpment
12	104.63	10.82	93.81	20	Toe of Escarpment
12	104.63	11.24	93.39	25	
12	104.63	12.52	92.11	30	**Water's Edge**
12	104.63	12.92	91.71	35	
12	104.63	13.38	91.25	40	
12	104.63	13.7	90.93	45	
12	104.63	13.83	90.8	47.9	**Breakwater**
13	104.63	6.28	98.35	12	Top of Escarpment
13	104.63	10.19	94.44	21	Toe of Escarpment
13	104.63	10.97	93.66	25	
13	104.63	11.77	92.86	30	
13	104.63	12.52	92.11	35	**Water's Edge**
13	104.63	13.01	91.62	40	
13	104.63	13.43	91.2	45	
13	104.63	13.66	90.97	49	**Breakwater**
14	104.63	4.92	99.71	9.4	Top of Escarpment
14	104.63	8.8	95.83	15	Toe of Escarpment
14	104.63	9.76	94.87	20	
14	104.63	10.3	94.33	25	
14	104.63	10.87	93.76	30	
14	104.63	11.41	93.22	35	
14	104.63	12.77	91.86	40	**Water's Edge**
14	104.63	12.8	91.83	45	
14	104.63	13.43	91.2	50	
14	104.63	13.68	90.95	53.5	**Breakwater**
15	104.63	4.61	100.02	7.75	Top of Escarpment
15	104.63	7.96	96.67	13	Toe of Escarpment
15	104.63	8.24	96.39	15	
15	104.63	8.78	95.85	20	
15	104.63	9.66	94.97	25	
15	104.63	10.04	94.59	30	
15	104.63	11.14	93.49	35	
15	104.63	11.78	92.85	40	
15	104.63	12.53	92.1	45	**Water's Edge**
15	104.63	13.02	91.61	50	
15	104.63	13.59	91.04	55	
15	104.63	13.72	90.91	58	**Breakwater**
16	104.63	6.27	98.36	20	Top of Escarpment
16	104.63	8.55	96.08	22.5	Toe of Escarpment
16	104.63	9	95.63	25	
16	104.63	9.74	94.89	30	
16	104.63	10.1	94.53	35	
16	104.63	10.92	93.71	40	
16	104.63	11.22	93.41	45	
16	104.63	12.46	92.17	50	**Water's Edge**
16	104.63	12.98	91.65	55	
16	104.63	13.39	91.24	60	
16	104.63	13.82	90.81	65	
16	104.63	13.97	90.66	66.9	**Breakwater**
17	104.63	8.94	95.69	34	Top of Escarpment
17	104.63	9.48	95.15	36	Toe of Escarpment
17	104.63	11.44	93.19	50	
17	104.63	11.84	92.79	55	
17	104.63	12.64	91.99	60	**Water's Edge**
17	104.63	13.2	91.43	65	
17	104.63	13.65	90.98	70	
17	104.63	13.75	90.88	71.2	**Breakwater**
18	104.63	8.3	96.33	54	Top of Escarpment
18	104.63	10.82	93.81	57	Toe of Escarpment
18	104.63	11.38	93.25	60	
18	104.63	11.88	92.75	65	
18	104.63	12.63	92	70	
18	104.63	12.82	91.81	73	**Water's Edge - Rock**

Transect 18 is beyond the BW on a rock outcrop

Final Elevation Survey
3-31-05

Transect	H.I.	F/S	ELEV (ft)	Distance from Pin (feet)	
03/31/2005					
1	107.03	10.01	97.02	3' 10"	Top of Escarpment
1	107.03	13.11	93.92	10	Toe of Escarpment
1	107.03	13.82	93.21	15	
1	107.03	14.34	92.69	20	
1	107.03	15.05	91.98	25	**Water's Edge begins**
1	107.03	15.33	91.70	30	
1	107.03	15.60	91.43	35	In Water
1	107.03	15.81	91.22	40	In Water
1	107.03	15.87	91.16	42	**Breakwater**
2	107.03	9.18	97.85	5	Top of Escarpment
2	107.03	11.43	95.60	7	Toe of Escarpment
2	107.03	13.20	93.83	15	
2	107.03	14.00	93.03	20	
2	107.03	14.82	92.21	25	**Water's Edge**
2	107.03	15.39	91.64	30	
2	107.03	15.71	91.32	35	
2	107.03	15.83	91.20	40	
2	107.03	15.95	91.08	43' 5"	**Breakwater**
3	107.03	9.51	97.52	9	Top of Escarpment
3	107.03	13.24	93.79	18	Toe of Escarpment
3	107.03	14.19	92.84	25	
3	107.03	14.90	92.13	30	**Water's Edge**
3	107.03	15.45	91.58	35	
3	107.03	15.67	91.36	40	
3	107.03	15.88	91.15	45	**Breakwater**
4	104.18	5.42	98.76	25	Top of Escarpment
4	104.18	11.10	93.08	25	Toe of Escarpment
4	104.18	12.35	91.83	35	
4	104.18	12.72	91.46	40	
4	104.18	13.02	91.16	45	
4	104.18	13.21	90.97	49.5	**Breakwater**
5	104.18	4.99	99.19	22.3	Top of Escarpment
5	104.18	11.11	93.07	30	Toe of Escarpment
5	104.18	12.35	91.83	35	**Water's Edge**
5	104.18	12.64	91.54	40	
5	104.18	12.96	91.22	45	
5	104.18	13.17	91.01	51	**Breakwater**
6	104.18	6.08	98.10	27.6	Top of Escarpment
6	104.18	11.84	92.34	28.4	Toe of Escarpment
6	104.18	12.84	91.34	40	
6	104.18	13.12	91.06	45	
6	104.18	13.47	90.71	50	
6	104.18	13.70	90.48	51.5	**Breakwater**
7	104.18	6.76	97.42	30	Top of Escarpment
7	104.18	12.13	92.05	31	Toe of Escarpment
7	104.18	12.96	91.22	40	
7	104.18	13.31	90.87	45	
7	104.18	13.54	90.64	49.5	**Breakwater**
8	104.18	4.48	99.70	14	Top of Escarpment
8	104.18	11.23	92.95	26	Toe of Escarpment
8	104.18	12.22	91.96	30	
8	104.18	12.76	91.42	35	
8	104.18	13.14	91.04	40	
8	104.18	13.36	90.82	45	
8	104.18	13.52	90.66	47.2	**Breakwater**
9	103.88	4.33	99.55	14	Top of Escarpment
9	103.88	11.15	92.73	22	Toe of Escarpment
9	103.88	12.16	91.72	30	**Water's Edge**
9	103.88	12.52	91.36	35	
9	103.88	12.89	90.99	40	
9	103.88	13.18	90.70	45	**Breakwater**
10	103.88	4.36	99.52	11	Top of Escarpment
10	103.88	10.33	93.55	16	Toe of Escarpment
10	103.88	10.96	92.92	20	
10	103.88	11.51	92.37	25	**Water's Edge**
10	103.88	12.10	91.78	30	
10	103.88	12.57	91.31	35	
10	103.88	12.84	91.04	40	
10	103.88	13.04	90.84	44	**Breakwater**

Transect	H.I.	F/S	ELEV (ft)	Distance from Pin (feet)	
03/31/2005					
11	103.88	4.50	99.38	7.9	Top of Escarpment
11	103.88	10.01	93.87	16	Toe of Escarpment
11	103.88	10.34	93.54	20	
11	103.88	11.19	92.69	25	
11	103.88	11.95	91.93	30	**Water's Edge**
11	103.88	12.37	91.51	35	
11	103.88	12.78	91.10	40	
11	103.88	12.98	90.90	45	
11	103.88	13.11	90.77	46.7	Breakwater
12	103.88	5.35	98.53	16	Top of Escarpment
12	103.88	9.88	94.00	20	Toe of Escarpment
12	103.88	10.19	93.69	25	
12	103.88	11.59	92.29	30	**Water's Edge**
12	103.88	12.15	91.73	35	
12	103.88	12.60	91.28	40	
12	103.88	13.05	90.83	45	
12	103.88	13.11	90.77	47.9	**Breakwater**
13	103.88	4.42	99.46	8	Top of Escarpment
13	103.88	9.52	94.36	21	Toe of Escarpment
13	103.88	10.32	93.56	25	
13	103.88	10.64	93.24	30	
13	103.88	11.64	92.24	35	**Water's Edge**
13	103.88	12.28	91.60	40	
13	103.88	12.67	91.21	45	
13	103.88	12.99	90.89	49	**Breakwater**
14	105.35	5.67	99.68	9.5	Top of Escarpment
14	105.35	9.61	95.74	15	Toe of Escarpment
14	105.35	10.49	94.86	20	
14	105.35	11.06	94.29	25	
14	105.35	11.60	93.75	30	
14	105.35	12.13	93.22	35	
14	105.35	13.08	92.27	40	**Water's Edge**
14	105.35	13.68	91.67	45	
14	105.35	14.26	91.09	50	
14	105.35	14.53	90.82	53.5	**Breakwater**
15	105.35	5.51	99.84	9	Top of Escarpment
15	105.35	8.65	96.70	13	Toe of Escarpment
15	105.35	9.05	96.30	15	
15	105.35	9.53	95.82	20	
15	105.35	10.46	94.89	25	
15	105.35	10.77	94.58	30	
15	105.35	11.80	93.55	35	
15	105.35	12.32	93.03	40	
15	105.35	13.23	92.12	45	**Water's Edge**
15	105.35	13.77	91.58	50	
15	105.35	14.34	91.01	55	
15	105.35	14.50	90.85	58	**Breakwater**
16	105.35	6.80	98.55	20	Top of Escarpment
16	105.35	8.89	96.46	22.5	Toe of Escarpment
16	105.35	9.68	95.67	25	
16	105.35	10.28	95.07	30	
16	105.35	10.85	94.50	35	
16	105.35	11.52	93.83	40	
16	105.35	12.44	92.91	45	
16	105.35	13.22	92.13	50	**Water's Edge**
16	105.35	13.68	91.67	55	
16	105.35	14.16	91.19	60	
16	105.35	14.64	90.71	65	**Breakwater**
17	105.35	7.44	97.91	34	Top of Escarpment
17	105.35	9.97	95.38	36	Toe of Escarpment
17	105.35	11.92	93.43	50	
17	105.35	12.91	92.44	55	**Water's Edge**
17	105.35	13.46	91.89	60	
17	105.35	13.84	91.51	65	
17	105.35	14.33	91.02	70	
17	105.35	14.38	90.97	71.2	**Breakwater**
18					Top of Escarpment
18					Toe of Escarpment
18					
18					
18					
18					**Water's Edge - Rock**

APPENDIX B

Plant Monitoring Data

APPENDIX A

Quadrat	Date	Feet from BW	Species	Type E, S, FL, T	Plant Depth inches	# Aq. Shoots	Photo	% Cover	Comments
PRE-PLANTING SURVEY - September 2, 2003 Survey Collectors : Allyson Childress; Time : 10:15 - 17:20; Pool Elevation 1037.93									
T01Q1	9/2/03	5		T				25	
T01Q2	9/2/03	26		T		9	P	5	
T01Q3	9/2/03	40		T				90	
T02Q1	9/2/03	2		NA		0	P		rock/mud
T02Q2	9/2/03	20		T				25	
T02Q3	9/2/03	35		T				75	
T03Q1	9/2/03	8.5		NA		0	P	0	rock/mud
T03Q2	9/2/03	25		T		6		10	flat spreading grass
T03Q3	9/2/03	45		T				100	
T04Q1	9/2/03	0		NA		0			mud
T04Q2	9/2/03	25		T				60	
T04Q3	9/2/03	41		T			P	25	
T05Q1	9/2/03	0		NA	1	0	P		mud
T05Q2	9/2/03	15		T				50	
T05Q3	9/2/03	44		T				80	
T06Q1	9/2/03	2		NA	2	0			
T06Q2	9/2/03	10		T		2	P	5	
T06Q3	9/2/03	35		T				90	
T07Q1	9/2/03	3		S	2	3		5	
T07Q2	9/2/03	12		T		2	P	5	
T07Q3	9/2/03	35		T				100	
T08Q1	9/2/03	2		S	1	4	P	5	one old growth, one green sprig
T08Q2	9/2/03	12		T		3		10	
T08Q3	9/2/03	?		T				100	
T09Q1	9/2/03	4		T	1	2		5	sub.T grass
T09Q2	9/2/03	15		T		2	P	5	button bush
T09Q3	9/2/03	?		T				90	
T10Q1	9/2/03	6		T		7	P	5	tiny grass sprigs, one lg
T10Q2	9/2/03	18				2		5	grass sprigs
T10Q3	9/2/03	40		T				100	
T11Q1	9/2/03	6		NA		0	P		mud
T11Q2	9/2/03	18	WW	E/T				20	WW, buttonbush sprig? Grasses
T11Q3	9/2/03	28	WW	E/T				60	grasses, WW
T12Q1	9/2/03	3		NA		0			mud
T12Q2	9/2/03	10		NA		2			terr wildflower, grass sprig
T12Q3	9/2/03	24	WW	E/T		NA	P	50	WW
T13Q1	9/2/03	?							
T13Q2	9/2/03	19	WW	T		3	P	10	WW, Cottonwood
T13Q3	9/2/03	?							
T14Q1	9/2/03	?							
T14Q2	9/2/03	21	WW	E		4	P		WW
T14Q3	9/2/03	34		T		NA		80	assorted terr.
T15Q1	9/2/03	0		NA		0	P		mud / sand
T15Q2	9/2/03	8		T		2			mud / sand
T15Q3	9/2/03	24	WW	E/T				60	
T16Q1	9/2/03	6		T		2			mud / sand 2 shoots T grass
T16Q2	9/2/03	22	WW	E/T			P	75	WW, T, Wildflower
T16Q3	9/2/03	37		T				90	
T17Q1	9/2/03	3		T		0	P		Sand
T17Q2	9/2/03	18	WW	E/T		6			WW, grass
T17Q3	9/2/03	27		T				50	
T18Q1	9/2/03	8	WW	E		2	P		
T18Q2	9/2/03	21		T/E				50	
T18Q3	9/2/03	36		T				100	
T19Q1	9/2/03	0		NA		0			Sand
T19Q2	9/2/03	16		T			P	50	grass, dandelion
T19Q3	9/2/03	28		T				70	grass, other
		No. Species count	**1**						

APPENDIX A

Quadrat	**Date**	**Feet from BW**	**Species**	**Type** E, S, FL, T	**Plant Depth** inches	**# Aq. Shoots**	**Photo**	**% Cover**	**Comments**
June 25, 2004 Survey Collectors : Owen Mills & Phillip Freeman Time : 10:15 - 17:20; Pool Elevation 1038.64									
* indicates we changed site distance from orig. escarpment site to a site in-water									
T01Q1	6/25/04	5	WW	E	6	1			1 ww 1 dead bulrush
T01Q2	6/25/04	26		T		0	P	20	
T01Q3*	6/25/04	10		T	3	0			
T02Q1	6/25/04	2		T	7	0	P	75	Big Bul just Out of sample
T02Q2	6/25/04	20		T		0			
T02Q3*	6/25/04	10		T	3	0		5	
T03Q1	6/25/04	8.5	Bul	E/T	1	3	P	5	Bul
T03Q2	6/25/04	25		T		0		5	
T03Q3*	6/25/04	2		T	7	0		40	
T04Q1	6/25/04	0		T	7	0		40	
T04Q2	6/25/04	25		T		0		100	
T04Q3*	6/25/04	10		T		0	P	5	
T05Q1	6/25/04	0		T	7	0	P	40	Large Bul Out on each side of sample
T05Q2	6/25/04	15				0			Big stump
T05Q3*	6/25/04	10		T	2	0		30	
T06Q1	6/25/04	2		T	12	0		10	
T06Q2	6/25/04	10	Junc	E/T	4	2	P	5	
T06Q3	6/25/04	35		T		0			Rocky
T07Q1	6/25/04	3		T	10			25	
T07Q2	6/25/04	12		T	2	0	P		
T07Q3	6/25/04	35				0			
T08Q1	6/25/04	2		T	11	0	P	5	
T08Q2	6/25/04	12		T	2	0		15	
T08Q3	6/25/04	Escarp				0			
T09Q1	6/25/04	4	WW , Bul	E/T	10	8			
T09Q2	6/25/04	15	WW	E/T		1	P		
T09Q3*	6/25/04	10	Bul	E/T	3	8			
T10Q1	6/25/04	6			4	0	P		mud
T10Q2	6/25/04	18			0	0			mud
T10Q3*	6/25/04	2			6	0			WW just Out
T11Q1	6/25/04	6	Bul	E	6	1	P		Bul
T11Q2	6/25/04	18			0	0			
T11Q3	6/25/04	10		T	4	0			
T12Q1	6/25/04	3		T		0	P		
T12Q2	6/25/04	10	Bul	E/T	1	1			
T12Q3*	6/25/04	15	Bul	E		2	P		
T13Q1*	6/25/04	2	WW	E	9	3			
T13Q2	6/25/04	19		T		0	P		
T13Q3*	6/25/04	10				0			Bul and Spike rush just out
T14Q1*	6/25/04	10		T		0	P		
T14Q2	6/25/04	21		T		0	P		
T14Q3*	6/25/04	2		T	7	0		40	
T15Q1	6/25/04	0	WW	E/T	9	1	P	20	
T15Q2	6/25/04	8		T		0			
T15Q3	6/25/04	24	WW	E		2			
T16Q1	6/25/04	6	WW	E/T	7	3		20	
T16Q2	6/25/04	22	Junc	E		1	P		rocks
T16Q3*	6/25/04	2		T	9	0		10	
T17Q1	6/25/04	3	Junc , Bul	E	5	3	P	40	Thick bulrush & Spikerush
T17Q2	6/25/04	18				0			rocks
T17Q3*	6/25/04	10		T		0			
T18Q1	6/25/04	8					P		Beyond Breakwater
T18Q2	6/25/04	21							Beyond Breakwater
T18Q3	6/25/04	36							Beyond Breakwater
T19Q1	6/25/04	0							Beyond Breakwater
T19Q2	6/25/04	16					P		Beyond Breakwater
T19Q3	6/25/04	28							Beyond Breakwater
		No. Species	**4**			**40**	**Total No. Shoots**		

APPENDIX A

Quadrat	Date	Feet from BW	Species	Type E, S, FL, T	Plant Depth inches	# Aq. Shoots	Photo	% Cover	Comments
Dec 8, 2004 Survey Collectors : Owen Mills & Scott Shellenberger Time : 10:30 - 12:30; Pool Elevation 1039.77									
Note: Water level is up 2 feet from when the site was planted.									
* indicates we changed site distance from orig. escarpment site to a site in-water									
** moved due to erosion on escarpment									
T01Q1	12/8/04	5				0			
T01Q2	12/8/04	26				0	P		
T01Q3*	12/8/04	10				0			
T02Q1	12/8/04	2	Bul	E		3	P		1 Plant
T02Q2	12/8/04	20		T		0			2 T Plants
T02Q3*	12/8/04	10	Bul	E		1			1 Plant
T03Q1	12/8/04	8.5				0	P		
T03Q2	12/8/04	25				0			
T03Q3*	12/8/04	2	Bul	E		3			1 Plant
T04Q1	12/8/04	0				0			
T04Q2**	12/8/04	23				0			Escarp moved, changed to 23 feet
T04Q3*	12/8/04	10				0			
T05Q1	12/8/04	0	Bul	E		8		30	
T05Q2	12/8/04	15				0			
T05Q3*	12/8/04	10				0			
T06Q1	12/8/04	2	WW			1			
T06Q2	12/8/04	10				0			
T06Q3	12/8/04	35				0			
T07Q1	12/8/04	3				0			
T07Q2	12/8/04	12				0			
T07Q3	12/8/04	35				0			
T08Q1	12/8/04	2				0			
T08Q2	12/8/04	12				0			
T08Q3	12/8/04	Escarp				0			
T09Q1	12/8/04	4				0			
T09Q2	12/8/04	15				0			
T09Q3*	12/8/04	10				0			
T10Q1	12/8/04	6	Bul	E		2			1 plant, common bulrush
T10Q2	12/8/04	18				0			
T10Q3*	12/8/04	2				0			
T11Q1	12/8/04	6	Bul	E		1			1 plant
T11Q2	12/8/04	18				0			
T11Q3	12/8/04	10				0			
T12Q1	12/8/04	3	HT , Bul	E		2			common Bulrush and Horsetail
T12Q2	12/8/04	10				0			
T12Q3*	12/8/04	15				0			
T13Q1*	12/8/04	2				0			
T13Q2	12/8/04	19				0			
T13Q3*	12/8/04	10				0			
T14Q1*	12/8/04	10				0			
T14Q2	12/8/04	21				0			
T14Q3*	12/8/04	2		T		0			
T15Q1	12/8/04	0	Bul	E		1			common Bulrush
T15Q2	12/8/04	8				0			
T15Q3	12/8/04	24		T				50	
T16Q1	12/8/04	6				0			
T16Q2	12/8/04	22				0			
T16Q3*	12/8/04	2				0			
T17Q1	12/8/04	3				0			
T17Q2	12/8/04	18				0			
T17Q3*	12/8/04	10				0			
T18Q1	12/8/04	8				0			Beyond Breakwater
T18Q2	12/8/04	21				0			Beyond Breakwater
T18Q3	12/8/04	36				0			Beyond Breakwater
T19Q1	12/8/04	0				0			Beyond Breakwater
T19Q2	12/8/04	16				0			Beyond Breakwater
T19Q3	12/8/04	28				0			Beyond Breakwater
		No. Species	**3**			**22**	**Total No. Shoots**		

APPENDIX A

Quadrat	Date	Feet from BW	Species	Type E, S, FL, T	Plant Depth inches	# Aq. Shoots	Photo	% Cover	Comments
July 15, 2005 Survey Collectors : Owen Mills & Megan Sprowls Time : 9:45 - 12:30; Pool Elevation 1038.57									
* indicates we changed site distance (6-25-04) from orig. escarpment site to a site in-water									
** moved due to erosion on escarpment (12-8-04)									
T01Q1	7/15/05	5				0			
T01Q2	7/15/05	26	Grass	Terr		0	P		
T01Q3*	7/15/05	10				0			Aquatics on every side of this Quadrat
T02Q1	7/15/05	2	Pondweed		6"		P	15	
			WW		"	6			
			Chara		"	0			
T02Q2	7/15/05	20	Forbs	Terr		0			
T02Q3*	7/15/05	10				0			
T03Q1	7/15/05	8.5	Pondweed	Submersed	2"	4	P		
T03Q2	7/15/05	25		Terr					
T03Q3*	7/15/05	2	Softstem	Emergent	7"	2			
			WW	Emergent	"	3			
T04Q1	7/15/05	0	Pondweed	Submersed	8"			10	
T04Q2**	7/15/05	23				0			
T04Q3*	7/15/05	10	Pondweed	Submersed			P	25	
T05Q1	7/15/05	0	Softstem	Emergent	10"	14	P		4' tall
			WW	Emergent	"	8			
T05Q2	7/15/05	15	3 Square	Emergent	0"	3			2' tall
T05Q3*	7/15/05	10	3 Square	Emergent	3"	1			
T06Q1	7/15/05	2				0			
T06Q2	7/15/05	10				0	P		
T06Q3	7/15/05	35				0			
T07Q1	7/15/05	3	Chara	Submersed	8"	0			
T07Q2	7/15/05	12				0	P		
T07Q3	7/15/05	35				0			
T08Q1	7/15/05	2	Chara	Submersed	14"	0	P		
T08Q2	7/15/05	12	Chara	Submersed	10"	0			
T08Q3	7/15/05	Escarp				0			
T09Q1	7/15/05	4				0			Pondweed along transect
T09Q2	7/15/05	15				0	P		
T09Q3*	7/15/05	10				0			
T10Q1	7/15/05	6				0	P		
T10Q2	7/15/05	18				0			
T10Q3*	7/15/05	2				0			
T11Q1	7/15/05	6				0	P		
T11Q2	7/15/05	18				0			
T11Q3	7/15/05	10				0			
T12Q1	7/15/05	3				0	P		
T12Q2	7/15/05	10				0			
T12Q3*	7/15/05	15				0	P		
T13Q1*	7/15/05	2				0			
T13Q2	7/15/05	19				0	P		
T13Q3*	7/15/05	10	Softstem	Emergent	0"	8			These are somewhat protected by breakw
T14Q1*	7/15/05	10				0			Remaining Waddles are short and
T14Q2	7/15/05	21		Terr		0	P		below the water line unlike in Zone 1
T14Q3*	7/15/05	2	WW		9"	4			
			Pondweed		"			20	
			Chara		"	0			
T15Q1	7/15/05	0				0	P		
T15Q2	7/15/05	8				0			
T15Q3	7/15/05	24				0			
T16Q1	7/15/05	6				0			
T16Q2	7/15/05	22	Sedge	Emergent	+24" above	2	P		2 plant groups of 21 stems, ~ 2 feet tall
T16Q3*	7/15/05	2	Chara	Submersed	12"			10	
T17Q1	7/15/05	3	Chara	Submersed	8"	0	P		
T17Q2	7/15/05	18				0			
T17Q3*	7/15/05	10				0			
T18Q1	7/15/05	8					P		Beyond Breakwater
T18Q2	7/15/05	21							Beyond Breakwater
T18Q3	7/15/05	36							Beyond Breakwater
T19Q1	7/15/05	0							Beyond Breakwater
T19Q2	7/15/05	16							Beyond Breakwater
T19Q3	7/15/05	28							Beyond Breakwater
		No. Species	**5**						
						55	**Total No. Shoots**		

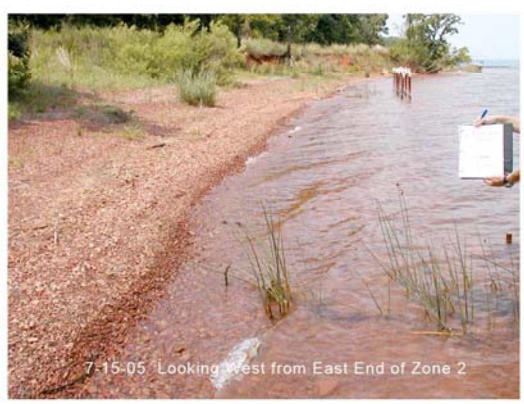
APPENDIX C

Plant Monitoring Photos

Quadrat Locations are delineated in Figure 15

First Plant Assessment
9-2-03

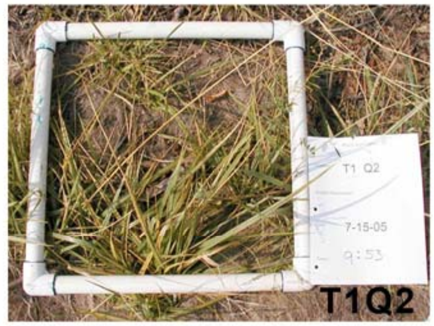
Final Plant Assessment
7-15-05



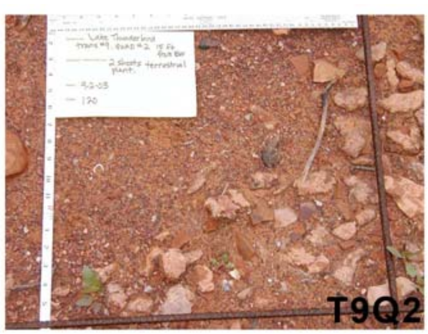
First Plant Assessment 9-2-03

T4Q3 was on the Escarpment and not duplicated

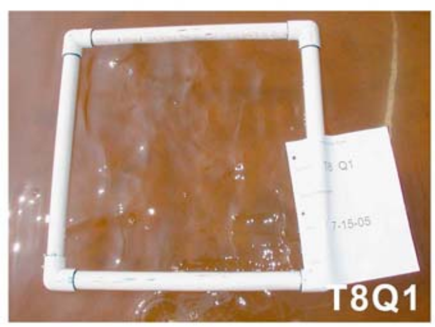
Final Plant Assessment 7-15-05

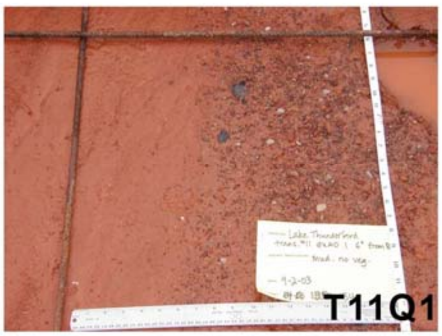


First Plant Assessment
9-2-03

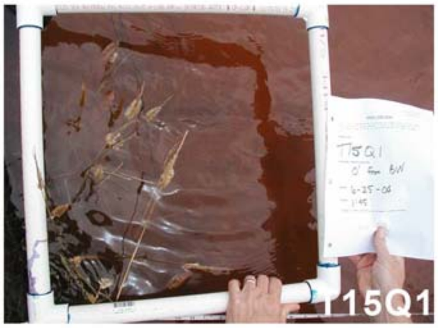


Final Plant Assessment
7-15-05



First Plant Assessment 9-2-03	Final Plant Assessment 7-15-05
	
	
	
	

Second Plant Assessment
6-25-04
(First Assessment Photos unavailable)



Final Plant Assessment
7-15-05