E C O L O G I C A L   R E V I E W

Black Bayou Culverts Hydrologic Restoration
CWPPRA Priority Project List 9
(State No. CS-29, Federal No. CS-16)

July 09, 2003

by
Kyle F. Balkum
Coastal Restoration Division
Louisiana Department of Natural Resources

contributions from
Mitch Andrus
Coastal Restoration Division
Louisiana Department of Natural Resources
and
Quin Kinler
National Resources Conservation Service
United States Department of Agriculture

ECOLOGICAL REVIEW

Black Bayou Culverts Hydrologic Restoration

In August 2000, the Louisiana Department of Natural Resources initiated the Ecological Review to improve the likelihood of restoration project success. This is a process whereby each restoration project's biotic benefits, goals, and strategies are evaluated prior to granting construction authorization. This evaluation utilizes monitoring and engineering information, as well as applicable scientific literature, to assess whether or not, and to what degree, the proposed project features will cause the desired ecological response.

Introduction:

The Black Bayou Culverts Hydrologic Restoration project is intended to provide additional drainage for the Mermentau Lakes sub-basin by restoring the hydrologic connection to Black Bayou. The proposed project involves construction of an optimal number of 10' x 10' box culverts under LA Highway 384 which bisects Black Bayou upstream of its confluence with the Calcasieu River (Figure 1). The restored drainage pattern is expected to decrease the depth and duration of flooding events which are assumed to be contributing to marsh degradation within the sub-basin.

I. Goal Statement:

The goal of the project is to maintain or improve wetland plant health and productivity in the predominantly fresh marshes of the Mermentau Lakes sub-basin.

II. Strategy Statement:

Reduce the duration of marsh flooding events through the construction of an optimal number of 10' x 10' box culverts under LA Highway 384.

III. Strategy-Goal Relationship:

When drainage opportunities exist (i.e., when water levels are higher on the east end of the structure), the culverts will provide a conduit for draining water from the sub-basin, potentially lowering water levels in the project area. This is expected to maintain or improve wetland plant health and productivity, which is thought to have been negatively affected by prolonged submergence.

IV. Project Feature Evaluation:

Engineering Evaluation by Mitch Andrus

In order to evaluate and optimize the proposed culvert structure at Black Bayou and LA Highway 384, a set of engineering calculations was produced by the Natural Resource Conservation Service (NRCS). These calculations rely on hourly water level data from the Calcasieu Lock structure. Simultaneous readings were taken east and west of the lock, making head difference calculations possible. Seven time periods between the years 1993 and 2000 were chosen by NRCS for the culvert analysis because the marsh was considered to be flooded from 14 to 28 consecutive days during those periods.

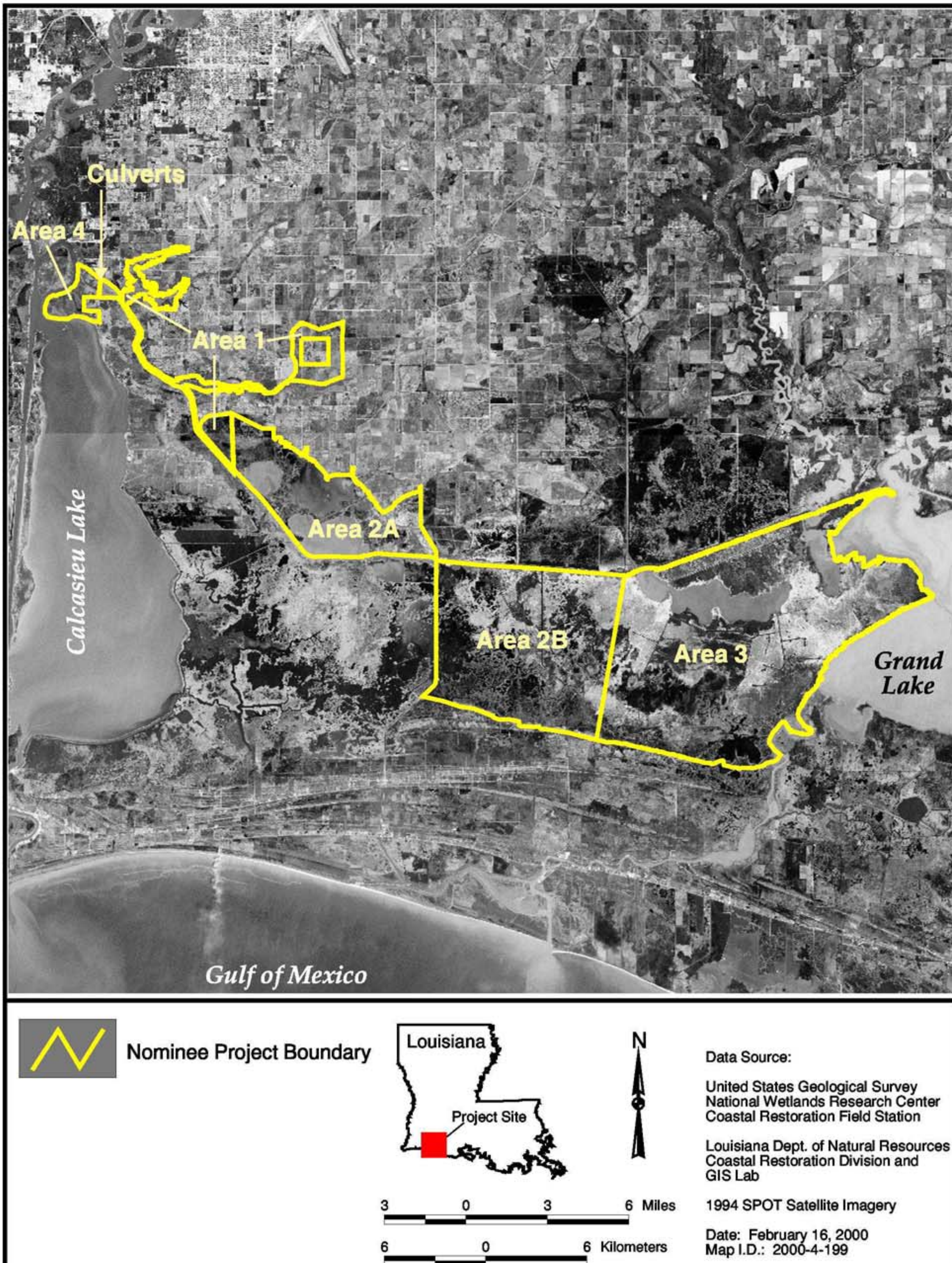

Figure 1. Black Bayou Culverts Hydrologic Restoration (State No. CS-29, Federal No. CS-16)

The culverts analyzed would be designed to operate only when the water levels on the inside of the Mermentau Lakes sub-basin (east side of the Calcasieu Lock) are higher than those on the outside of the Mermentau Lakes sub-basin (west side of the Calcasieu Lock). The culverts would have flap gates at the exits that would close at high tides to eliminate the possibility of saltwater intrusion from Calcasieu Lake. The flap gates would also be locked closed when interior water levels drop below 0.8 ft NAVD-88. The dimensions of the culverts are 10' x 10', resulting in a flow area of 100 ft^2 each, and 100 ft in length.

A spreadsheet was created to estimate flows through the proposed culverts and the corresponding volumetric change within the sub-basin. The spreadsheet employed widely used and appropriate culvert flow formulas. The values for formula coefficients, flap gate head loss, and affected acreage were all valid for this level of preliminary design. The spreadsheet also incorporated an hourly reduction factor calculation applied to the original data to account for the effects of the culvert flow and predicted what the stage would have been if the culverts were actually in place. The adjusted stage values were used to predict culvert flow for each hour. An optimization was also performed by varying the number of culverts and evaluating the different degrees of performance. It was determined that the number of culverts could be increased to ten before reaching the point of diminishing returns (i.e., the point at which the addition of further culverts resulted in the reduction of water flow per culvert).

According to the spreadsheet, the maximum water elevation reduction achieved by the ten culverts, during the seven time periods analyzed, was 0.5 ft. The average reduction achieved was 0.27 ft. These calculations were based on the assumptions that the Mermentau Lakes sub-basin is a closed system and that uniform sheet flow is occurring over the entire marsh. Although these conditions were assumed for the calculations, they do not always reflect actual field conditions. For example, the mouth of the Mermentau River is connected to the Gulf of Mexico making its stage affected by tidal movement. Even though the river is locked off by the Catfish Point control structure, tidal inflow can bypass the structure through smaller bayous and more gradually through the marsh during high tide conditions. Review of the spreadsheet calculations reveals that the culverts have potential to move water out of the sub-basin and possibly lower the stage, however, when actual field conditions are considered, the reduction may be less than predicted and localized rather than basin-wide.

V. Assessment of Goal Attainability:

The goal of the project is to maintain or improve wetland plant health and productivity in the predominantly fresh marshes of the Mermentau Lakes sub-basin. An assessment of whether or not the proposed project will achieve this goal can not be adequately performed due to the lack of information regarding plant health and productivity within the project area. Unfortunately, no scientific evidence has been uncovered which equivocally attests to the current condition of the marsh in question. In an attempt to discern how and if prolonged marsh inundation has negatively affected wetland plant health and productivity in the sub-basin, an intensive literature review was conducted, as well as an analysis of hourly water level data from the east side of Calcasieu Lock. Also, information from the United States Geological Survey's Coastal Change Analysis Program (C-CAP) was utilized to identify recent landscape changes in the Black Bayou Culverts Hydrologic

Restoration project area. The results of the literature review, data analysis, and C-CAP are presented below in detail.

The Assessment of Goal Attainability concludes with a presentation of the NRCS spreadsheet results.

Literature Review

To better understand the physiological effect of high water levels on fresh and intermediate marsh vegetation, a comprehensive literature review was undertaken. The following list includes summaries of all relevant scientific literature and is also presented in tabular format (see Table 1) to provide for easier comparison between studies. If additional information is brought forth, a revaluation would be necessary.

- Baldwin, et al. (1996) conducted two greenhouse experiments to determine the effect of inundation on seed banks of intermediate marshes dominated by *Paspalum vaginatum* (seashore paspalum), *Sagittaria lancifolia* (bulltongue), or *Spartina patens* (marshhay cordgrass). After a simulated flooding event in which water levels were maintained 4–5 cm above the soil surface for 48 days, species richness and seedling number were significantly reduced. The exceptions were *S. lancifolia* and *Eleocharis parvula* (dwarf spikerush), "for which the effect of inundation was not significant."

- Bandyopadhyay, et al. (1993) transferred *S. patens* plants from a marsh to a laboratory and maintained salinities at < 1 ppt while subjecting the plants to three intensities of sediment reduction ranging from -115 mV to +475 mV (+475 was the aerated treatment) for 33 days. The reduction in soil redox potential (Eh) did not alter net photosynthesis or leaf conductance, but did significantly reduce root dry weight and shoot dry weight in the hypoxia treatments (+235 and -115 mV Eh). The root/shoot ratio showed significant differences among the Eh treatments, further evidence that root growth of *S. patens* was reduced at low Eh.

- Gough and Grace (1998) simulated flooding treatments in the field by lowering sods 10 cm below marsh surface from June 1993–July 1995 (~26 months). The study site was a fresh/intermediate marsh dominated by *S. lancifolia* and *S. patens* and was sampled 7 times throughout the course of the experiment (7/93, 10/93, 4/94, 7/94, 10/94, 4/95, and 7/95). Species density decreased in the lowered sods as compared to controls (3 out of the 7 dates were found to be significant). Aboveground biomass also decreased, but not significantly so. Gough and Grace concluded that *S. lancifolia* was "relatively tolerant of flooding."

- Grace and Ford (1996) conducted a field experiment in an intermediate marsh dominated by *S. lancifolia* from October 26, 1992 through June 3, 1993 (221 days). The effect of inundation on *S. lancifolia* was tested by permanently lowering sods 20 cm below marsh surface. The control sods were flooded for an estimated 71% of the time compared to the

Table 1. Summary of studies documenting the physiological effect of high water levels on fresh and intermediate marsh vegetation (Arranged alphabetically by author).

Citation	Study Site	Species	Depth & Duration of Flooding Treatment	Results/Discussion
Baldwin, McKee, and Mendelssohn (1996)	Greenhouse	*Eleocharis parvula* *Paspalum vaginatum* *Sagittaria lancifolia* *Spartina patens*	4-5 cm; 48 days	Species richness and seedling number were significantly reduced. "The exceptions were *E. parvula* and *S. lancifolia*, for which the effect of inundation was not significant."
Bandyopadhyay, Pezeshki, DeLaune, and Lindau (1993)	Laboratory	*Spartina patens*	Anaerobic soil conditions; 33 days	Reduced soil Eh did not alter net photosynthesis or leaf conductance, but did significantly reduce root dry weight and shoot dry weight in the hypoxia treatments.
Gough and Grace (1998)	Fresh/Intermediate marsh in Pearl River WMA	*Sagittaria lancifolia* *Spartina patens*	10 cm; Jun. 1993–Jul. 1995 (~26 months)	Species density and aboveground biomass decreased. Concluded that *S. lancifolia* was relatively flood tolerant.
Grace and Ford (1996)	Intermediate marsh near Pass Manchac	*Sagittaria lancifolia*	20 cm; Oct. 1992–Jun. 1993 (221 days)	An increase in aboveground biomass was observed. Concluded that "increased flooding of up to 20 cm is insufficient to have long-term detrimental effects" on *S. lancifolia*.
Howard and Mendelssohn (1995)	Intermediate marsh in Barataria Preserve Unit of Jean Lafitte NHPP	*Sagittaria lancifolia*	7.5 & 15 cm; Apr. 1989–Jul. 1990 (~15 months); Not flooded during low water periods.	Treatments resulted in significantly greater mean leaf heights. Root biomass was significantly reduced when subjected to the 15 cm increase in water depth, but above ground and total belowground biomass were not affected.
Lessmann, Mendelssohn, Hester, and McKee (1997)	Greenhouse	*Panicum hemitomon* *Spartina patens*	Varying depths (0–39 cm); 57-58 days	Leaf elongation rates for both species declined, but no significant population effect was identified.
McKee and Mendelssohn (1989)	Fresh marsh near Lac des Allemands	*Sagittaria lancifolia* *Panicum hemitomon* *Leersia oryzoides*	10 cm; May 1986–Sep. 1986 (one growing season)	Stem density and biomass were significantly reduced in *P. hemitomon*, but *S. lancifolia* and *L. oryzoides* "appeared to be unaffected."
	Greenhouse	*Panicum hemitomon* *Leersia oryzoides*	10 cm; 35 days	*P. hemitomon* was not significantly affected by treatment, but stem elongation in *L. oryzoides* appeared inhibited.
Pezeshki and DeLaune (1990)	Laboratory	*Spartina patens*	Anaerobic soil conditions; 5-6 days	Root elongation was "severely inhibited" shortly after reducing soil Eh, but returned to previous levels within two days of treatment end (in moderately reduced conditions).
Pezeshki, DeLaune, and Patrick (1987)	Greenhouse	*Sagittaria lancifolia*	5 cm; 45 days	Mean stomatal conductance and net photosynthesis were decreased 19% and 26% respectively.
Pezeshki, Matthews, and DeLaune (1991)	Laboratory	*Spartina patens*	Anaerobic soil conditions; 22 days	Root growth of *S. patens* was severely inhibited shortly after reducing soil Eh in the range of -50 to +70 mV.
Webb and Mendelssohn (1996)	Intermediate marsh ~4 km west of LaRose, LA	*Sagittaria lancifolia*	15 cm; May1993–Oct. 1993 (155 days)	Live biomass of the lowered sods was significantly reduced.

lowered sods which were continuously flooded throughout the experiment. An increase in aboveground biomass (not significant) was observed in the lowered treatments as compared to the control. Grace and Ford conclude that "increased flooding of up to 20 cm is insufficient to have long-term detrimental effects" on *S. lancifolia*.

- Howard and Mendelssohn (1995) lowered sods in an intermediate marsh (dominated by *S. lancifolia* and *S. patens)* 7.5 and 15 cm from April 1989–July 1990 (approximately 15 months) to simulate two levels of increased flooding stress. Both treatments resulted in significantly greater mean leaf heights compared to controls. Root biomass was significantly reduced when subjected to the 15 cm increase in water depth, but above ground and total belowground biomass were not affected. It should be noted that during this experiment the lowered sods lacked standing water during low-water periods.

- Lessmann, et al. (1997) conducted a greenhouse experiment on populations of *Panicum hemitomon* (maidencane) and *S. patens* to determine growth responses to a simulated flooding event. *Panicum hemitomon* populations were flooded continuously for 58 days at varying depths (13, 26, and 39 cm above the soil surface). *Spartina patens* populations were also flooded continuously for 57 days at varying depths (0 and 39 cm above the soil surface). Leaf elongation rates for both species declined, but no significant population effect was identified.

- McKee and Mendelssohn (1989) conducted both field and greenhouse experiments on the following three plant species: *S. lancifolia, P. hemitomon*, and *Leersia oryzoides* (rice cutgrass). The field experiment consisted of lowering sods 10 cm for one growing season (May 1986–September 1986). Stem density and biomass were significantly reduced in *P. hemitomon*, but *S. lancifolia* and *L. oryzoides* "appeared to be unaffected." The greenhouse experiment simulated a flooding event by maintaining water levels 10 cm above the soil surface for 35 days. *Panicum hemitomon* was not significantly affected by this treatment, but stem elongation in *L. oryzoides* appeared to be inhibited. The authors concluded that the effect of prolonged inundation on fresh marsh communities "may depend on the species composition and relative flood tolerance of the dominant species."

- Pezeshki and DeLaune (1990) transplanted *S. patens* plants from a marsh to a laboratory and subjected them to alternating cycles of low and high Eh. Root elongation was "severely inhibited" shortly after reducing soil redox levels from high (> +500 mV) to low (-100 to -200 mV). Root growth was reduced when Eh fell below +350 mV, followed by complete cessation of root growth at -100 mV. Following a 5 day treatment in moderately reduced conditions (0 to -150 mV), root elongation returned to previous levels within 2 days. After a 5 day treatment in strongly reduced conditions (< -180 mV), root growth recovered more slowly. Pezeshki and DeLaune concluded that *S. patens* requires "periods of drainage during the growing season to allow increase in soil Eh thus providing favorable conditions" for root development.

- Pezeshki, et al. (1987) transplanted *S. lancifolia* plants into a greenhouse and simulated a flood event by maintaining water levels 5 cm above soil surface for 45 days. Following the treatment, they found that mean stomatal conductance and net photosynthesis were decreased 19% and 26% respectively, compared to control plants. The reduction in mean stomatal conductance was not statistically significant, but the flooding did affect net photosynthesis significantly.

- Pezeshki, et al. (1991) found that root growth of *S. patens* plants, transplanted from the marsh to a laboratory, was severely inhibited shortly after reducing soil Eh in the range of -50 to +70 mV (O_2 is not present in most flooded soils at Eh below +350 mV).

- Webb and Mendelssohn (1996) conducted a field experiment in an intermediate marsh dominated by *S. lancifolia*. Sections of marsh were lowered 15 cm below marsh surface and monitored for approximately one growing season (May 1993–October 1993 ~ 155 days). Live biomass of the lowered sods was significantly reduced (Eh for the lowered sod was approximately -200 mV compared to approximately -125 mV for the control).

This collection of studies indicates that certain species of fresh and intermediate marsh vegetation, when subjected to continuous flooding treatments for as little as 35 days, experienced physiological changes such as reduced stem elongation, inhibited root growth, and decreased stomatal conductance and net photosynthesis. Studies which simulated extended periods of flooding, ranging from one to three growing seasons, documented decreases in species density, stem density, aboveground biomass, and root biomass. Conversely, other experiments found no change in net photosynthesis, leaf conductance, and stem elongation when the very same vegetation species were subjected to relatively short flooding treatments (33–35 days). Even more confounding are the experiments which found an increase in aboveground biomass or detected no change in aboveground and belowground biomass or stem density when subjecting plants to longer flooding treatments, ranging from 5–15 months in length (Grace and Ford 1996, Howard and Mendelssohn 1995, McKee and Mendelssohn 1989). These seemingly conflicting results indicate that a greater understanding of the effect of inundation on fresh–intermediate marsh vegetation is needed.

<u>Data Analysis</u>

In an effort to gain a general understanding of water levels in the Mermentau Lakes sub-basin, an analysis of hourly water level data was undertaken. Data compiled from the east side of Calcasieu Lock were utilized because of the locks close proximity to the proposed project features and physical location within the Lakes sub-basin. These data, recorded from July 1987–May 2000, were only useful for our analysis if we accepted the assumption that water levels recorded at the lock are representative of water levels in the project area. The hourly water level data was evaluated in relation to a mean marsh elevation which was determined in a joint survey conducted by NRCS, the Louisiana Department of Natural Resources (LDNR), and Lonnie G. Harper and Associates, Inc., on August 17 and October 9, 2001. The mean marsh elevation (n=293) was obtained by placing the survey rod on soil containing living roots, among living stems of the dominant marsh vegetation species (Steyer, et al. 1995). We assumed, for the sake of our analysis, that the calculated mean marsh elevation of 1.124 ± 0.311 ft NAVD-88 was a true representative of marsh elevations in the project area.

The water level data are summarized in Tables 2 and 3. Those water level readings equal to or greater than 1.12 ft NAVD-88 were summed on an annual basis and presented as a percentage of the whole for that year (Table 2). These percentages give an indication of how long the marsh was inundated during that particular year. It should be noted that in the years of 1987, 1992, 1995, and 2000 a substantial portion (> 60%) of the data record was missing. In order to identify periods of continuous inundation, the supposed cause of decreased plant health and productivity, thirty consecutive days was selected as the minimum period of time to be considered as a "flooding event." This number is somewhat arbitrary, but physiological changes were noted in the experiments previously cited when certain marsh vegetation species were subjected to simulated flooding events as short as 35 days in length (McKee and Mendelssohn 1989). The data revealed that nine such flooding events occurred from July 1987 to May 2000 (Table 3). In contrast, the water level was lower than the assumed marsh elevation for a minimum of 30 consecutive days on 16 such occasions. Are nine periods of prolonged inundation over a nearly thirteen year period of record sufficient to cause decreased plant health and productivity? Our current understanding of this hydrologic regime and its effect on vegetation precludes us from confidently answering this question.

Table 2. Annual summary of hourly water level readings from the east side of Calcasieu Lock in relation to an assumed marsh elevation.

Year	n	n $ 1.12' NAVD	% of Total
1987	2,492 (28.4%)	723	29.0%
1988	6,866 (78.4%)	2,882	42.0%
1989	6,926 (79.1%)	1,769	25.5%
1990	6,489 (74.1%)	1,852	28.5%
1991	6,393 (73.0%)	4,680	73.2%
1992	2,879 (32.9%)	1,725	59.9%
1993	7,338 (83.8%)	4,183	57.0%
1994	4,539 (51.8%)	1,629	35.9%
1995	2,725 (31.1%)	1,254	46.0%
1996	8,082 (92.3%)	3,185	39.4%
1997	6,116 (69.8%)	3,310	54.1%
1998	8,402 (95.9%)	4,386	52.2%
1999	6,635 (75.7%)	1,923	29.0%
2000	3,383 (38.6%)	528	15.6%
Total	**79,265 (64.6%)**	**34,029**	**42.9%**

Table 3. Periods of time in which water levels continuously exceeded or were lower than the assumed marsh elevation for thirty consecutive days or longer (July 1987–May 2000).

Periods water levels exceeded 1.12' NAVD		Periods water levels were lower than 1.12' NAVD	
Date	**Days**	**Date**	**Days**
Aug. 25, 1988–Sep. 24, 1988	30	Aug. 18, 1987–Oct. 29, 1987	72
Jan. 09, 1991–Feb. 14, 1991	36	Oct. 16, 1988–Dec. 25, 1988	70
Apr. 11, 1991–Jun. 05, 1991	55	Feb. 03, 1989–Mar. 27, 1989	52
Jan. 07, 1993–Feb. 06, 1993	30	Aug. 15, 1989–Dec. 14, 1989	121
Apr. 07, 1993–May 13, 1993	36	Jun. 08, 1990–Sep. 13, 1990	97
Jun. 19, 1993–Jul. 19, 1993	30	Sep. 23, 1990–Nov. 27, 1990	65
Sep. 21, 1996–Nov. 09, 1996	49	Jul. 23, 1993–Oct. 29, 1993	98
Feb. 13, 1997–Mar. 20, 1997	35	Nov. 06, 1994–Dec. 06, 1994	30
Sep. 10, 1998–Nov. 05, 1998	56	Mar. 06, 1996–Apr. 11, 1996	36
		Apr. 30, 1996– Jun. 27, 1996	59
		Sep. 09, 1997–Oct. 11, 1997	32
		Oct. 14, 1997–Nov. 24, 1997	41
		May 16, 1998–Jul. 02, 1998	47
		Jul. 06, 1998–Aug. 21, 1998	46
		Jul. 27, 1999–Feb. 25, 2000	213
		Feb. 26, 2000–Apr. 10, 2000	43
Total events	**9**	**Total events**	**16**
Avg. length of the 9 events	**39.7 days**	**Avg. length of the 16 events**	**70.1 days**

Coastal Change Analysis Program

The Coastal Change Analysis Program was conducted by the Spatial Analysis Branch of the United States Geological Survey National Wetlands Research Center. Land cover data derived from Landsat Thematic Mapper (TM) imagery were analyzed to identify large scale changes to wetlands in the Mermentau Basin. Landsat TM images with a spatial resolution, or pixel size, of 25 meters were acquired between the fall and winter months (October–February) of 1990, 1993, and 1996 for land cover classification. An accuracy assessment for the change points from 1990 to 1996 resulted in an overall accuracy of 90% (Ramsey et al. 2001).

The results of C-CAP's analysis seem to indicate that wetland loss and gain, from 1990–1996, occurred in small isolated patches within the Black Bayou Culverts Hydrologic Restoration project area (Figure 2). During this time period, wetlands remained relatively stable. These data preclude a definitive examination of the current state of wetland plant health and productivity in the Mermentau Lakes sub-basin, but C-CAP does represent the most current land cover change analysis available.

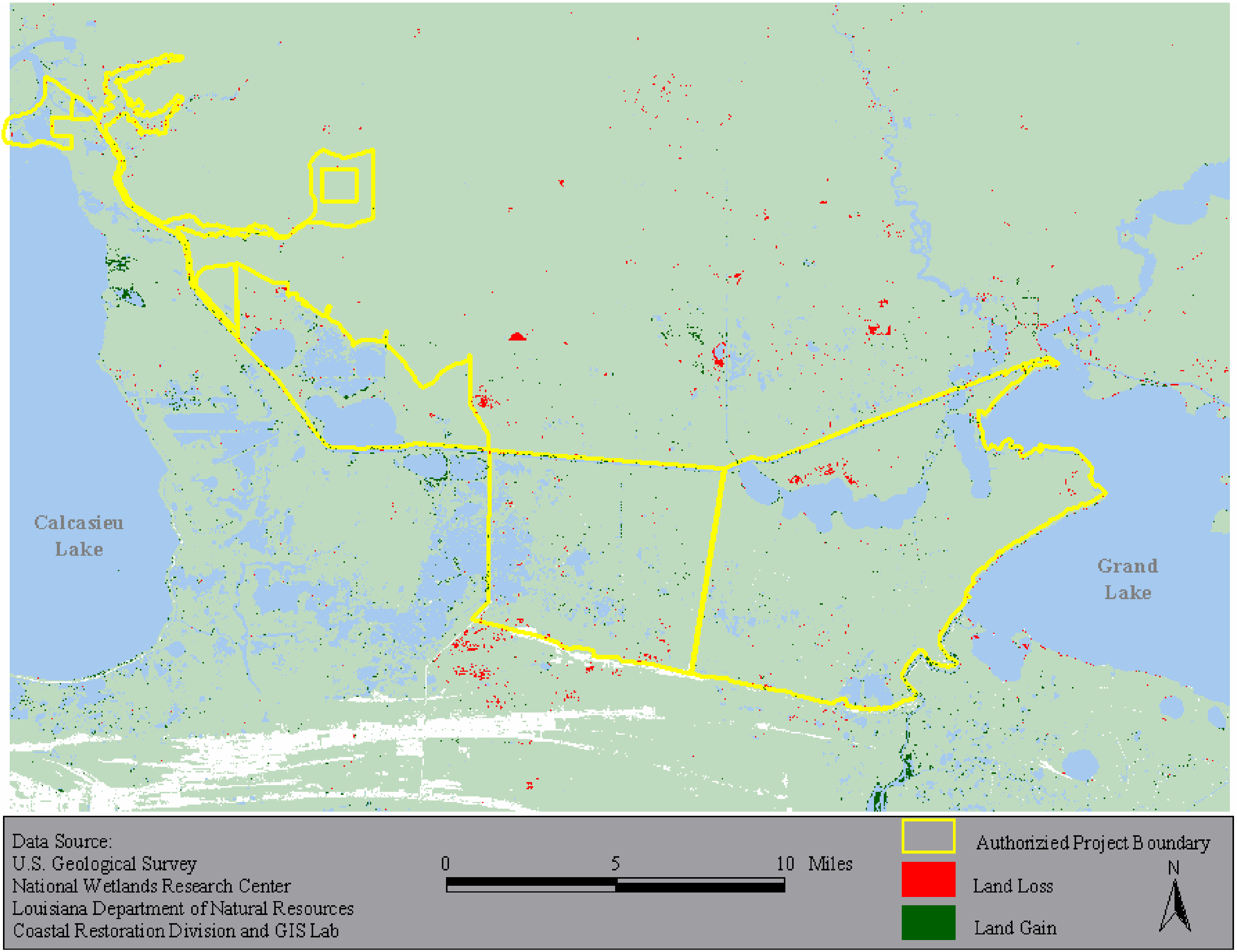

Figure 2. Land loss and land gain from 1990 to 1996 in the Black Bayou Culverts Hydrologic Restoration (CS-29) project area.

Spreadsheet Results

The proposed strategy for achieving the project goal is to reduce the duration of marsh flooding events through the construction of 10, 10' x 10' box culverts under LA Highway 384. The previously evaluated NRCS spreadsheet was used to predict the effect of structure operation on water levels in the project area. Ten periods of continuous marsh inundation, ranging from approximately 15 to 66 days in duration, were evaluated with the spreadsheet and the results are presented below in Table 4.

Table 4. Spreadsheet results of the operation of 10, 10' x 10' box culverts in Black Bayou at LA Highway 384.

Actual Dates and Durations of Marsh Inundation without Culverts		Predicted Durations of Marsh Inundation with Culverts
Date	**Days**	**Days**
Jan. 07, 1993–Feb. 06, 1993	29.8	15.3
Apr. 06, 1993–May 13, 1993	36.9	5.0
Jun. 19, 1993–Jul. 07, 1993	18.4	< 1.0
Aug. 21, 1996–Sep. 05, 1996	15.2	< 1.0
Sep. 20, 1996–Nov. 25, 1996	65.6	23.7
Feb. 23, 1997–Mar. 19, 1997	24.3	5.1
Apr. 24, 1997–May 14, 1997	20.5	< 3.0
Jan. 09, 1998–Feb. 03, 1998	24.3	5.8
Sep. 10, 1998–Nov. 04, 1998	55.1	18.5
May 03, 2000–May 20, 2000	17.7	10.7

* 1994 and 1995 were not analyzed due to the relatively high percentage of unavailable hourly water level readings, 48.2% and 68.9%, respectively.

Summary of Findings

The purpose of the Ecological Review is to improve the likelihood of project success by assessing whether or not, and to what degree, the proposed project features will cause the desired ecological response. The assessment of whether or not the Black Bayou Culverts Hydrologic Restoration project will achieve the goal of maintaining or improving wetland plant health and productivity has been a challenge. The hydrology of the project area is extremely complex, as is the ecology of fresh and intermediate marshes characteristic of the project area. The Ecological Review has not revealed information sufficient to confirm or refute whether the proposed project will achieve the project goals.

References

Baldwin, A. H., K. L. McKee, and I. A. Mendelssohn. 1996. The influence of vegetation, salinity, and inundation on seed banks of oligohaline coastal marshes. American Journal of Botany. 83(4): 470-479.

Bandyopadhyay, B. K., S. R. Pezeshki, R. D. DeLaune, and C. W. Lindau. 1993. Influence of soil oxidation-reduction potential and salinity on nutrition, N-15uptake, and growth of *Spartina patens*. Wetlands. 13(1): 10-15.

Gough, L. and J. B. Grace. 1998. Effects of flooding, salinity and herbivory on coastal plant communities, Louisiana, United States. Oecologia. 117: 527-535.

Grace, J. B. and M. A. Ford. 1996. The potential impact of herbivores on the susceptibility of the marsh plant *Sagittaria lancifolia* to saltwater intrusion in coastal wetlands. Estuaries. 19(1): 13-20.

Howard, R. J. and I. A. Mendelssohn. 1995. Effect of increased water depth on growth of a common perennial freshwater–intermediate marsh species in coastal Louisiana. Wetlands. 15(1): 82-91.

Lessmann, J. M., I. A. Mendelssohn, M. W. Hester, and K. L. McKee. 1997. Population variation in growth response to flooding of three marsh grasses. Ecological Engineering. 8:31-47.

McKee, K. L. and I. A. Mendelssohn. 1989. Response of a freshwater marsh plant community to increased salinity and increased water level. Aquatic Botany. 34: 301-316.

Pezeshki, S. R. and R. D. DeLaune. 1990. Influence of sediment oxidation-reduction potential on root elongation in *Spartina patens*. Acta OEcologica. 11(3): 377-383.

Pezeshki, S. R., R. D. DeLaune, and W. H. Patrick, Jr. 1987. Effects of flooding and salinity on photosynthesis of *Sagittaria lancifolia*. Marine Ecology - Progress Series. 41: 87-91.

Pezeshki, S. R., S. W. Matthews, and R. D. DeLaune. 1991. Root cortex structure and metabolic responses of *Spartina patens* to soil redox conditions. Environmental and Experimental Botany. 31(1): 91-97.

Ramsey, E. W., III, G. A. Nelson, and S. K. Sapkota. 2001. Coastal change analysis program implemented in Louisiana. Journal of Coastal Research. 17(1): 53-71.

Steyer, G. D., R. C. Raynie, D. L. Steller, D. Fuller, and E. Swenson. 1995. Quality management plan for Coastal Wetlands Planning, Protection, and Restoration Act monitoring program. Open-file series no. 95-01 (Revised June 2000). Baton Rouge: Louisiana Department of Natural Resources, Coastal Restoration Division. 97 pp.

Webb, E. C. and I. A. Mendelssohn. 1996. Factors affecting vegetation dieback of an oligohaline marsh in coastal Louisiana: Field manipulation of salinity and submergence. American Journal of Botany. 83(11): 1429-1434.