Designing a Constructed Wetland for the Detention of Agricultural Runoff for Water Quality Improvement

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The goal of this study was to construct a wetland that would detain runoff from a 162-ha watershed for the purposes of improving water quality. The volume of runoff that needed to be detained was determined to be that amount coming off the 162-ha watershed consisting of 146 ha of cultivated crop land and 16 ha of pasture that exceeded the amount that would have come off of the watershed in its natural, forested state. The Soil Conservation Service (now the Natural Resource Conservation Service [NRCS]) runoff curve number method was used to estimate runoff from the watershed in its natural, forested state and in its current state of cultivated crop land and pasture. The design of the constructed wetland was accomplished using the natural topography of the wetland site and the design criteria for a sediment containment system developed by NRCS. The SPAW (Soil-Plant-Atmosphere–Water Field & Pond Hydrology) computer model was used to model depth and volume in the wetland to determine if the constructed wetland design would accommodate typical runoff events. Construction of the wetland occurred over a 4-mo period. The capabilities of the system were verified when Hurricane Rita deposited above-normal rainfall to the wetland site area. The wetland was able to accommodate this event, allowing flow through the system for 9 d, followed by continued detention of remaining runoff for water quality improvement.

Nearly 7 million metric tons of nitrogen (N) in commercial fertilizers are applied annually in the Mississippi-Atchafalaya River Basin, which makes up nearly 41% of the contiguous USA (Goolsby and Battaglin, 2000). The Mississippi and Atchafalaya Rivers drain the basin, carrying runoff through Louisiana into the northern Gulf of Mexico at the state’s coast. It has been estimated that these two rivers discharge 1.57 million metric tons of N into the Gulf of Mexico annually, nearly 90% of the total N discharged into the Gulf (Goolsby et al., 1999). The influx of N and other nutrients stimulates algal growth. As algae and other organic matter settles to the bottom of the Gulf, the decomposition process depletes oxygen, resulting in a hypoxic zone off the Louisiana coast each summer. This zone reached a record high area of 22,000 km² in 2002 (Bierman et al., 2007). Increases in the use of fertilizer, particularly N fertilizer, in the Mississippi-Atchafalaya River basin have been implicated as the cause of the increasing size of the hypoxic zone (Donner and Scavia, 2007). Mitsch et al. (2001) examined strategies that would help reduce N loading to the Gulf of Mexico and identified the creation and restoration of wetlands between farmland and streams and rivers as one likely effective method.

During the colonial period (1780s), it was estimated that there were 65,540 km² of wetlands in Louisiana (Dahl, 1990). Over a 200-yr period, as the population of Louisiana grew, wetlands, regarded as having little value, were drained or filled at a rate of 150 km² yr⁻¹ so they could be used for agriculture or urban development. By the 1980s, the area once occupied by wetlands had declined 46% to 35,550 km². However, between 1986 and 1997, the rate of annual wetland loss in the USA declined dramatically and has shown a small increase from 1998 to 2004, largely due to increasing awareness of the environmental importance of wetlands (Dahl, 2000; Dahl, 2005). The reversal in the decline is due to restoration of existing wetlands and creation of new wetlands. Because 80% of the loss of coastal wet-
lands in the USA has occurred in Louisiana, much of the current restoration efforts are focused on these wetlands. The importance of all wetlands in Louisiana was made dramatically apparent as a result of Hurricanes Rita and Katrina.

Extensive research over the past 40 yr has shown that wetlands serve an important role in improving water quality (Reed, 1993; Wolverton et al., 1983). It is therefore not surprising that as the number of wetlands declined in Louisiana, so has the water quality of many of the state’s water bodies. The Louisiana Department of Environmental Quality (LDEQ) has divided the Red River Basin in Louisiana into 71 subsegments (LDEQ, 1999). The 2004 Water Quality Inventory Report published by LDEQ indicated that 75% of the water bodies within these subsegments were impaired, meaning that they could not fully support their designated use for fish and wildlife propagation. The Flat River subsegment 1004006 begins north of Shreveport and stretches southeasterly to Loggy Bayou, encompassing nearly 303 km², 60% of which is agricultural (Fig. 1). This subsegment was listed as impaired on the 2004 303(d) List for Louisiana and was ranked as priority 2 for maximum daily load development. No specific nonpoint sources (NPS) were listed in the final 2004 303(d) list, but because most of land use in this subsegment is agricultural, it is likely this enterprise is a significant contributor to NPS pollution to the Flat River (EPA, 2008). A recent EPA publication, “TMDL for Dissolved Oxygen and Nutrients for Flat River Subsegment 100406” (EPA, 2008), compared ambient N and phosphorus (P) of the Flat River during the summer to LDEQ reference streams in the South Central Plain Ecosystem and concluded that 62 and 30% reduction in total P and N loads, respectively, would be needed for the concentration of these nutrients in the Flat River to be similar to the reference stream averages (EPA, 2008). This publication also indicated that 75 to 92.5% of the NPS loads to the Flat River needed to be reduced to maintain a 5 mg L⁻¹ dissolved oxygen criteria during the summer.

Conducted wetlands provide an effective and economical way of improving effluent water quality through biological and physical means and are being used worldwide to clean effluent from municipalities, rural communities, single dwellings, and agricultural and urban storm runoff. Borin and Tocchetto (2007) showed over a 5-yr period that a wetland that received slightly more than 2000 kg ha⁻¹ of N, mostly from farmland drainage, discharged 206 kg ha⁻¹ of N over the 5-yr period, with an apparent removal efficiency of about 90%. Removal was mostly because of plant uptake (1110 kg ha⁻¹) and soil accumulation (570 kg ha⁻¹), with the contribution of denitrification being estimated at around 7%. Borin et al. (2001) demonstrated that wetlands reduced nitrate (NO₃⁻) by 95% and total dissolved solids by 30% in runoff from cropland. Reilly et al. (2000) obtained NO₃⁻ removal rates as high as 1000 mg NO₃⁻N m⁻² d⁻¹ in a 172-ha, free-surface wetland. In Maryland, Jordan et al. (2003) found that dry periods improved the performance of a wetland. In a year where drying periods occurred, a wetland removed 59% of the total P, 38% of the total N, and 41% of the total organic carbon it received. During a second year, which lacked a drying period, there was no significant (p > 0.05) net removal of total N or P, although 30% of the total organic carbon input was removed. In Ireland, Healy and Cawley (2002) demonstrated that a wetland removed 51% of the total N, 13% of the total P, and 84 to 90% of suspended solids and reduced biological oxygen demand by 49% in municipal runoff. They noted the formation of algal blooms during the growing season reduced P removal efficiency. Information on how much of the nutrients stored in plant tissue are subsequently released on decay is somewhat limited, but Vymazal (2007) suggests that this is an important part of the wetland nutrient cycle and that, although a portion is released back to the wetland waters, some are subjected to an enhancement of degradation processes provided by the above-water standing dead plant material and litter, and some may be translocated to living plant roots for uptake.

In 2003, funding was provided by LDEQ through Section 319(h) of the Federal Clean Water Act to design and construct a wetland to accommodate runoff from 162 ha. The primary objectives of this project were to determine if it was practical to construct a wetland of sufficient size to successfully detain runoff from 162 ha of agricultural land and to determine the effectiveness of this system in reducing nutrient, sediment, and pesticide loads of runoff before entering an impaired Louisiana water body.

Materials and Methods

Study Site Description

The constructed wetland site was located at Louisiana State University Agricultural Center’s Red River Research Station in northwest Louisiana south of Bossier City (32°24’54.51″N, 93°37’48.30″W). The Red River Research Station consists of 232 ha of agricultural land subdivided into 1.62- to 3.24-ha research blocks, where crops such as cotton, soybean, corn, grain sorghum, and wheat are grown. The station is located in LDEQ subsegment 100406 (Fig. 1). Runoff from approximately 162 ha of the station flows to the southeastern corner, where it enters Lay’s Bayou. It then flows to the Flat River, which is one of the water bodies within subsegment 100406 (Fig. 2). The Flat River is a tributary to the Red River, which flows south-southeast through Louisiana until it joins the Atchafalaya and Mississippi Rivers. The Red River drains 20,098 km² of land area in Louisiana and has the highest sediment load in the USA (Albertson and Patrick, 1996; Sauzier, 1998). Because the Flat River has been designated as an impaired water body and one of the suspected causes of that impairment is crop production, the southeast corner of the station was identified as an ideal location to construct a wetland to determine the potential for improving the water quality of discharge from agricultural lands prior to drainage into a state water body (Fig. 2).

Wetland Design

Design of the constructed wetland began by determining the amount of runoff that would be entering the system. The goal was to construct a wetland that would retain runoff from the 162-ha watershed consisting of 146 ha of cultivated crop land and 16 ha of pasture that exceeded the amount of runoff from the watershed in its natural, forested state. The intended function of the wetland was therefore twofold: (i) to physically detain the volume of runoff...
that was in excess of that present before clearing of trees and cultivating the land and (ii) to improve the quality of runoff from agricultural land before entering an impaired Louisiana water body.

The Soil Conservation Service (now Natural Resource Conservation Service [NRCS]) Curve Number (CN) method is a commonly used method to estimate the volume of surface runoff from a watershed (USDA-NRCS, 2004). The CN is a unitless, empirically derived value based on one of four hydrological soil groups, land use, surface conditions, and antecedent moisture conditions unique to a particular watershed. Soils grouped within a particular hydrologic group have similar runoff potential. The soils in the USA are placed into four groups: A, B, C, and D. The soil at this study site was type B, which has been described as having moderate infiltration and transmission rates when thor-

Fig. 1. Map showing the location of the project site (aerial photo) in relation to the Louisiana Department of Environmental Quality’s water quality segment 100406 (shaded area).

Fig. 2. Aerial view of the Red River Research Station located in northwest Louisiana showing the location of the constructed wetland.
ously wetted. Type B soils are moderately deep to deep, moderately well drained to well drained, and have moderately fine to moderately coarse textures (USDA-NRCS, 2009). The CN assumes that there is a proportional relationship between watershed runoff and retention (Ponce and Hawkins, 1996):

\[ F = \frac{Q}{S} P \]

where \( F \) is actual retention, \( S \) is potential retention, \( Q \) is actual runoff, and \( P \) is potential runoff or precipitation depth.

The value of \( P \) is equal to the amount of rainfall the watershed receives minus the initial abstraction (I), which is the proportion of rainfall that is intercepted, infiltrates into the soil, or accumulates as surface storage (Ponce and Hawkins, 1996). Initial abstraction is usually assumed to be a linear function of \( S \) (Gerla, 2007):

\[ I_a = 0.2S \]

The CN values range from 0 to 100; the greater the CN value, the greater the potential for runoff. A CN of 100 would indicate an impermeable watershed with 100% runoff (\( S = 0 \)); conversely, a CN of 0 would indicate a watershed in which \( I_a \) is 100 or 0% runoff. The basic equations for determining the CN in average conditions are:

\[ Q = \left( \frac{P - 0.2S}{P + 0.8S} \right)^2 \]

and in metric units

\[ CN = \frac{2540}{(S + 25.4)} \]

The CN method was used to quantify the amount of runoff from the watershed in both its original and present state. For the original, naturally forested condition on hydrologic soil group B, a CN of 55 was used to calculate runoff from all 162 ha of land. For current land conditions consisting of 146 ha of cultivated fields and 16 ha of pasture on the same soil hydrologic group, a weighted CN of 77 was used. Using the different curve numbers and other characteristics of the watershed (drainage area, hydraulic flow length, watershed slope, and historic rainfall amount and distribution), a computer program developed by NRCS for determining peak discharge as prescribed by the Engineering Field Handbook (USDA-NRCS, 2008) was used to estimate runoff and peak discharge for the watershed in both land uses. Tables 1 and 2 show the estimated runoff and peak discharge from the watershed in its natural state (CN = 55) and in its current state (CN = 77), respectively, after 1-, 2-, 5-, 10-, 25-, 50-, and 100-yr storm events. In its current state, the watershed length is greater than in the natural state because runoff from 146 ha of cultivated fields and 16 ha of pasture were grassed, they were included as part of the overall sediment containment system. The ditches were 488, 366, and 427 m in length and approximately 3 m in width, providing an approximate total of 3900 m² of grassed buffer before entering the wetland system. At the points where the ditches entered the wetland system, the depth was increased to 2 m to serve as sediment basins. From the basins, runoff enters a shallow wetland approximately 2.13 ha in area and then a deeper wetland with an area of 0.92 ha. A diagram showing the proposed wetland design in relation to topography of the area is shown in Fig. 3. A wetland designed to retain runoff from 162 ha after a 2-yr, 24-h rainfall event of 11.2 cm would need to retain 40,303 m³ of runoff (Table 3). The average depth of the shallow wetland shown in Fig. 4 was 0.53 m, giving a total volume of 11,348 m³. The three sediment

Guidelines established by Dupoldt et al. (1993) were used to design the constructed wetland system. According to these guidelines, the goal is to construct a nutrient and sediment control system (NSCS) between a watershed and a nearby lake or stream that serves as a biological filter and physicochemical treatment system that reduces \( P \), \( N \), organic matter, bacteria, and fine sediments from watershed runoff, thereby minimizing the impact of nonpoint-source pollution on the receiving water body. Dupoldt et al. (1993) suggested a combination of a sediment basin, a grassed buffer, a vegetated shallow pond, a deep pond, and a vegetated “polishing” area. The suggested sizes of the components of the NSCS depend on the size of the watershed area contributing runoff. Table 4 shows the suggested sizes increased in direct proportion to Dupoldt’s recommendation for each sediment basin component needed to accommodate runoff from 162 ha.
basins located at the point where the three drainage ditches entered the shallow wetland can collectively contain approximately 1530 m³. The average depth of the designed deep wetland was 2.3 m, resulting in an average volume of 17,959 m³. The total retention volume available in the constructed wetland was therefore 30,837 m³. However, the three grassed drainage ditches leading to the wetland totaled 1280 m in length, with an average width of approximately 3 m and an average depth of approximately 0.53 m, providing an estimated 2081 m³ of additional runoff retention. Therefore, the total retention capacity of the proposed constructed wetland was 32,918 m³, short of the volume required for a 2-yr, 24-h rainfall event of 11.2 cm but very close to the 33,121 m³ required for a 1-yr, 24-h rainfall event of 9.4 cm. In addition, the most complete weather data collected over 28 yr at a weather station in Calhoun, Louisiana, located approximately 134 km away (32°30’48” N, 92°20’53” W) and identified by the NRCS Water and Climate Center as the nearest weather station with the necessary continuous long-term data, indicated that 24-h rainfall events were less than 2.54 cm 95% of the time. The proposed wetland design should therefore provide adequate storage at least 95% of the time.

Modeling Runoff Events

To determine if the constructed wetland design would accommodate typical runoff events, the SPAW (Soil-Plant-Atmosphere–Water Field & Pond Hydrology) computer model was used to determine if the constructed wetland design would accommodate typical runoff events, the SPAW (Soil-Plant-Atmosphere–Water Field & Pond Hydrology) computer model was used (Saxton and Willey, 2005). The model estimates daily vertical one-dimensional water depth resulting from all major hydrologic processes and can be used to determine wetland inundation and frequency. The SPAW model has field and pond components. The field component uses the NRCS runoff curve number method to estimate runoff and infiltration from the difference between precipitation amount and estimated runoff and soil and crop descriptions to determine the daily flux of water into and out of the system (Saxton and Willey, 2004). The pond component uses daily SPAW field hydrology estimations to determine daily pond inflow, outflow, and storage. Using the SPAW model, the hydrology of 138 ha of cultivated crop land and 24 ha of pasture was simulated for 28 continuous years. Although the model was run on this initial estimate of 138 ha of cultivated crops and 24 ha of pasture, the actual areas were later determined to be 146 ha of Table 1. Estimated runoff and peak discharge calculated for CN = 55 (Natural Watershed State) after 1-, 2-, 5-, 10-, 25-, 50-, and 100-yr storm events (rainfall type II).†

<table>
<thead>
<tr>
<th>Storm number</th>
<th>Frequency, yr</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-h rainfall, cm</td>
<td>9.4</td>
<td>11.2</td>
<td>13.7</td>
<td>16.3</td>
<td>18.5</td>
<td>20.6</td>
<td>22.6</td>
<td></td>
</tr>
<tr>
<td>I/P ratio</td>
<td>0.44</td>
<td>0.37</td>
<td>0.3</td>
<td>0.26</td>
<td>0.22</td>
<td>0.2</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>I/P ratio used</td>
<td>0.44</td>
<td>0.37</td>
<td>0.3</td>
<td>0.26</td>
<td>0.22</td>
<td>0.2</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Runoff, cm</td>
<td>1.07</td>
<td>1.78</td>
<td>3.02</td>
<td>4.45</td>
<td>5.89</td>
<td>7.24</td>
<td>8.69</td>
<td></td>
</tr>
<tr>
<td>Runoff, ha-m</td>
<td>1.73</td>
<td>2.88</td>
<td>4.89</td>
<td>7.19</td>
<td>9.54</td>
<td>11.72</td>
<td>14.06</td>
<td></td>
</tr>
<tr>
<td>Unit peak discharge, m³ s⁻¹ ha⁻¹ cm⁻¹</td>
<td>0.0030</td>
<td>0.0033</td>
<td>0.0036</td>
<td>0.0038</td>
<td>0.0039</td>
<td>0.0039</td>
<td>0.0040</td>
<td></td>
</tr>
<tr>
<td>Peak discharge, m³ s⁻¹</td>
<td>0.51</td>
<td>0.96</td>
<td>1.76</td>
<td>2.72</td>
<td>3.68</td>
<td>4.62</td>
<td>5.58</td>
<td></td>
</tr>
</tbody>
</table>

† Drainage area: 162 ha; watershed length: 610 m; watershed slope: 0.1%; time of concentration: 3.94 h (calculated value).

Table 2. Estimated runoff and peak discharge calculated for CN = 77 (Current Watershed State) after 1-, 2-, 5-, 10-, 25-, 50-, and 100-yr storm events (rainfall type II).

<table>
<thead>
<tr>
<th>Storm number</th>
<th>Frequency, yr</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>24-h rainfall, cm</td>
<td>9.4</td>
<td>11.2</td>
<td>13.7</td>
<td>16.3</td>
<td>18.5</td>
<td>20.6</td>
<td>22.6</td>
<td></td>
</tr>
<tr>
<td>I/P ratio</td>
<td>0.16</td>
<td>0.14</td>
<td>0.11</td>
<td>0.09</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>I/P ratio used</td>
<td>0.16</td>
<td>0.14</td>
<td>0.11</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Runoff, cm</td>
<td>4.01</td>
<td>5.41</td>
<td>7.52</td>
<td>9.73</td>
<td>11.79</td>
<td>13.64</td>
<td>15.52</td>
<td></td>
</tr>
<tr>
<td>Runoff, ha-m</td>
<td>6.50</td>
<td>8.76</td>
<td>12.17</td>
<td>15.75</td>
<td>19.08</td>
<td>22.08</td>
<td>25.12</td>
<td></td>
</tr>
<tr>
<td>Unit peak discharge, m³ s⁻¹ ha⁻¹ cm⁻¹</td>
<td>0.0055</td>
<td>0.0056</td>
<td>0.0057</td>
<td>0.0058</td>
<td>0.0058</td>
<td>0.0058</td>
<td>0.0058</td>
<td></td>
</tr>
<tr>
<td>Peak discharge, m³ s⁻¹</td>
<td>3.57</td>
<td>4.93</td>
<td>6.99</td>
<td>9.12</td>
<td>11.04</td>
<td>12.77</td>
<td>14.53</td>
<td></td>
</tr>
</tbody>
</table>

† Drainage area: 162 ha; watershed length: 793 m; watershed slope: 0.1%; time of concentration: 5.73 h (calculated value).

Table 3. Estimated storage volumes needed to detain runoff from 162 ha of the watershed in its current state after local 1-, 2-, 5-, and 10-yr 24-hr storm events.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Amount</th>
<th>q_o/q_i†</th>
<th>V_s/V_r</th>
<th>V_s</th>
</tr>
</thead>
<tbody>
<tr>
<td>yr</td>
<td>cm</td>
<td>ha-m</td>
<td>m³</td>
<td>m³</td>
</tr>
<tr>
<td>1</td>
<td>9.4</td>
<td>0.143</td>
<td>0.510</td>
<td>3.312</td>
</tr>
<tr>
<td>2</td>
<td>11.2</td>
<td>0.195</td>
<td>0.460</td>
<td>4.030</td>
</tr>
<tr>
<td>5</td>
<td>13.7</td>
<td>0.251</td>
<td>0.415</td>
<td>5.047</td>
</tr>
<tr>
<td>10</td>
<td>16.3</td>
<td>0.298</td>
<td>0.381</td>
<td>6.002</td>
</tr>
</tbody>
</table>

† q_o, post-runoff conditions; q_i, pre-runoff conditions; V_r, runoff volume; V_s, storage volume.

Table 4. Minimum size components for a nutrient containment system designed to accommodate 162 ha of runoff based on criteria established by Dupoldt et al. (1993).

<table>
<thead>
<tr>
<th>Contributing area</th>
<th>Sediment basin</th>
<th>Graded buffer</th>
<th>Vegetated shallow pond</th>
<th>Deep pond</th>
<th>Vegetated “polishing” area grassed</th>
</tr>
</thead>
<tbody>
<tr>
<td>ha</td>
<td>m²</td>
<td>m</td>
<td>m²</td>
<td>m²</td>
<td></td>
</tr>
<tr>
<td>162</td>
<td>743</td>
<td>6503</td>
<td>213</td>
<td>6503</td>
<td>10,405</td>
</tr>
</tbody>
</table>

(Saxton and Willey, 2005). The model estimates daily vertical one-dimensional water depth resulting from all major hydrologic processes and can be used to determine wetland inundation and frequency. The SPAW model has field and pond components. The field component uses the NRCS runoff curve number method to estimate runoff and infiltration from the difference between precipitation amount and estimated runoff and soil and crop descriptions to determine the daily flux of water into and out of the system (Saxton and Willey, 2004). The pond component uses daily SPAW field hydrology estimations to determine daily pond inflow, outflow, and storage. Using the SPAW model, the hydrology of 138 ha of cultivated crop land and 24 ha of pasture was simulated for 28 continuous years. Although the model was run on this initial estimate of 138 ha of cultivated crops and 24 ha of pasture, the actual areas were later determined to be 146 ha of...
cultivated crops and 16 ha of pasture. Separate SPAW simulations were conducted for the shallow and deep wetland components. Profiles for both wetlands input into SPAW are shown in Table 5.

The shallow wetland had a maximum depth of 1.07 m and a maximum area of 1.82 ha at that depth; the deep wetland had a maximum depth of 2.74 m and a maximum area of 4.05 ha at that depth (Table 5). The maximum depths and areas of both wetlands input into SPAW represent a situation in which the principal spillway is exceeded but just before the wetland containment structures are overtopped. A seepage rate of 2.5 mm d\(^{-1}\) was assumed for wetlands and runoff calculated for 138 ha of cultivated crop land and 24 ha of pasture. Simulations of runoff and wetland depth and volume are shown in Fig. 5 and 6, respectively. The point at which water began to flow out of the shallow pond was set at 0.5 m for the SPAW simulation. The simulation indicated that water level in the shallow pond would remain below this level 54% of the time over a 28-yr period. The point at which water began to flow out of the deep wetland was set at 1.8 m for the SPAW simulation. The simulation indicated that water level in the deep pond would remain below this level 51% of the time over a 28-yr period.

The effectiveness of a constructed wetland in improving the water quality of agricultural runoff increases with the time runoff remains in the wetland system before being released to a receiving water body (Jing et al., 2001; Sakadevan and Bavor, 1999; Zhang et al., 2008). Plug-flow conditions and first-order removal equations
are often used to predict the breakdown of pesticides and nutrients as well as the removal of pathogenic microorganisms (Alvord and Kadlec, 1996; Jamieson et al., 2007; Jing et al., 2002; Kadlec, 1999; Khatiwada and Polprasert, 1999; Moore et al., 2001):

\[ C_{\text{out}} = C_{\text{in}} e^{-K_{t}T} \]

where \( C_{\text{out}} \) is the concentration (μg L\(^{-1}\)) of effluent from system, \( C_{\text{in}} \) is the initial (Day 0) measured concentration (μg L\(^{-1}\)) of influent to system, \(-K_{t}\) is the temperature-dependent first order decay rate constant (d\(^{-1}\)), and T is time (days).

The decay rate constant (\( K_{t} \)) is constituent specific and has been shown to be independent of temperature for some constituents (Rousseau et al., 2004). The half-life of a constituent, which is the time required to reduce the concentration of a constituent to half of its value at \( T = 0 \), has the following relationship to the constituent’s decay rate constant:

\[ T_{1/2} = \frac{\ln(2)}{K_{t}} = \frac{0.693}{K_{t}} \]

where \( T_{1/2} \) = half-life (days) (Rodgers and Dunn, 1992).

To obtain the desired half-life of a constituent, it is necessary that runoff from a watershed be captured and detained. However, a constructed wetland is a dynamic system that changes according to the rate and volume of inflow to the system, meaning that detention time is inherently variable. To maximize wetland detention time, 90° v-notch weirs were attached to two 1.2-m culverts connecting the shallow wetland to the deep wetland and to two 1.2-m culverts that transferred water from the deep wetland to Lays Bayou, which flowed to the Flat River (Fig. 2). The bottom v-notch of the shallow wetland weirs maintained water retention for depths up to 1 m and regulated flow up to 1.2 m.

![Fig. 5. SPAW (Soil-Plant-Atmosphere–Water Field & Pond Hydrology) simulation of watershed runoff entering the shallow wetland and resulting volume and depth with culvert and spillway crests.](image)

### Table 5. Wetland profile information used by SPAW† to produce simulations.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Area (ha)</th>
<th>Volume (ha-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shallow wetland</td>
<td>Deep wetland</td>
</tr>
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† Soil-Plant-Atmosphere–Water Field & Pond Hydrology.

The bottom v-notch of the deep wetland weirs maintained water retention for depths up to 1.8 m and regulated flow for depths to 2.1 m. Although the maximum shallow wetland area used for SPAW predictions was 1.8 ha, the topography of the shallow wetland area allowed for broader expansion nearly double that used for SPAW while maintaining the maximum 1-m depth.

### Construction and Testing of the Wetland System

Construction of the wetland system began in December of 2003 and was completed in April of 2004. Before the begin-
ning of construction, native wetland plants were collected from a natural wetland located approximately 10 km south of the constructed wetland site and transferred to an outdoor nursery to await the completion of the constructed wetland. The plants collected included rose mallow (Hibiscus lasiocarpos Cav.), delta duck potato (Sagittaria platyphylla (Engelm. J. G. Smith), erect burhead (Echinodorus rostratus (Nutt. Engelm. ex Gray), royal flatsedge (Cyperus elegans L.), marsh flatsedge (Cyperus pseudovegetus Steud.), and pickerel weed (Pontederia cordata L.). In addition to the native wetland plants, three cultivated wetland grass species were obtained from the NRCS Golden Meadows Plant Materials Center in Galiano, Louisiana. These included eastern gamagrass (Tripsacum dactyloides L.), ‘Alamo’ switchgrass (Panicum virgatum L.), and ‘Gulf Coast’ marsh-hay cordgrass (Spartina patens Aiton Muhl.). Transplanting of the native plants and cultivated grass species was conducted in May 2004, after construction of the wetland was completed. The native species were interspersed approximately 1 m apart in the shallow wetland. The grass species were placed in rows along the banks of the shallow wetland.

Over summer 2004, metal platforms were constructed along the path of runoff through the constructed wetland system. To monitor changes in water quality through the system, Teledyne ISCO Avalanche automatic water sampling stations were positioned on the platforms at four points along the system. Each sampler uses a Model 720 Submerged Probe Flow Module (Teledyne ISCO, Lincoln, NE) or a Model 750 Area Velocity Module (Teledyne ISCO) that uses a differential pressure transducer to measure the level of the flow stream and triggers the samplers to collect flow-proportioned water samples. The first sampler was placed near one of the three ditches that drained runoff from the 162 ha immediately before it entered the constructed wetland system. Samples from this location are analyzed to determine the quality of water entering the constructed wetland system. A second sampling station was located midway between the first sampling station and the shallow wetland. Because this drainage ditch flows through a pasture, it may contribute fecal coliform bacteria to the wetland system. By sampling at this point, the contribution of the pasture to the coliform content of runoff water can be determined. A third sampling station is located on the levee separating the shallow and deep wetland. This station samples water leaving the shallow wetland to determine improvements in water quality at this stage of the constructed wetland system. The fourth sampling station is located at the levee that separates the deep wetland from its point of egress. This station collects water samples from the deep wetland to determine improvements in the quality of water at the final stage of the constructed wetland system.

To monitor water quality of the shallow and deep wetlands continuously, two Hach Minisonde 4a Hydrolabs were suspended approximately 3 m from the weirs attached to the culverts and were positioned to monitor water quality parameters at a depth of 0.3 m. The hydrolabs constantly monitor pH, temperature, turbidity, conductivity, and dissolved oxygen.

**Results and Discussion**

**Wetland Performance**

On 24 Sept. 2005, Hurricane Rita made landfall as a Category 3 hurricane between Sabine Pass, Texas and Johnsons
Bayou, Louisiana. On 25 Sept. 2005, the hurricane passed over northwest Louisiana, depositing nearly 152 mm of rainfall. Water levels in the constructed wetland during this time are shown in Fig. 7. The Teledyne ISCO Avalanche automatic water samplers were programmed to begin sampling when flow through the v-notch weirs began and began recording water levels at that time. This event demonstrated that the constructed wetland functioned as it was designed, allowing flow for 11 to 12 d after this above-average rainfall event and then continuing the function of detaining runoff for water quality improvement.

The size of the constructed wetland area needed for detention of runoff from 162 ha was only 3.05 ha, so only 1.9% of total land area was needed for construction of the wetland.

One modification to the design process that may improve future applications would be low-flow release below the principal spillway inlet elevation in the large pond to increase available detention storage while maintaining a minimum permanent pool depth (e.g., 1.2 m). In summary, the steps taken in the constructed wetland design process in this study were:

1. Determine watershed drainage area to be treated.
2. Determine design storm to be handled (e.g., 1-yr, 24-h).
3. Calculate pre- and post-runoff conditions \( q_0, q_i \).
4. Calculate required detention storage \( V_s, V_r \).
5. Calculate NSCS requirements.
6. Size wetland cells based on Steps 4 and 5 calculations and site conditions.

**Conclusions**

The goal of this study was to construct a wetland that would retain runoff from a 162-ha watershed consisting of 146 ha of cultivated crop land and 16 ha of pasture that exceeded the amount of runoff from the watershed in its natural, forested state. Since its construction, the wetland has functioned as designed, providing runoff detention time necessary for water quality improvement while allowing flow through the system at times when watershed runoff is above average. The effectiveness of this system in improving water quality will be documented in a subsequent publication.

**References**


