# CHAPTER 334

## Hydraulic Controls on Tidal Wetlands

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## Abstract

Tidal wetlands have long been identified as critical habitats for many species of fish, birds, and other wildlife and are protected areas in many states. For these reasons, coastal projects which impact or destroy wetland areas are difficult to permit and often require substantial mitigation. An hydraulic design procedure is presented for the creation or improvement of wetlands based on flooding duration -- the percentage of time an area is inundated by tidal waters. This is followed by a sample application of the procedure to a recent mitigation project in Savannah, Georgia.

## Introduction

Tidal wetlands, sometimes called the oceans' nurseries, contain many habitats for both plants and animals. Among the many habitats that exist, the basic ones include open water, tidal flats, low marsh, high marsh, transitional wetlands, and highland (Fig. 1). These habitats are sensitively balanced for existing tidal conditions, wave climate, daily flooding duration, sedimentation rates, and climate (Kana et al., 1986). Perturbations of these factors over an extended period can result in the transformation of one habitat into another.

Because wetlands tend to exist in areas of limited topographic relief, transitions between habitats can be indistinct and often occur over some distance, making precise location of boundaries difficult. Nevertheless, it is generally recognized that the character of flooding controls species distribution, with some wetland species preferring infrequent and irregular inundation, while others have adapted to frequent flooding. As a result, many studies have been undertaken to define wetland boundaries (Teal, 1958; Redfield, 1972; Nixon, 1982).

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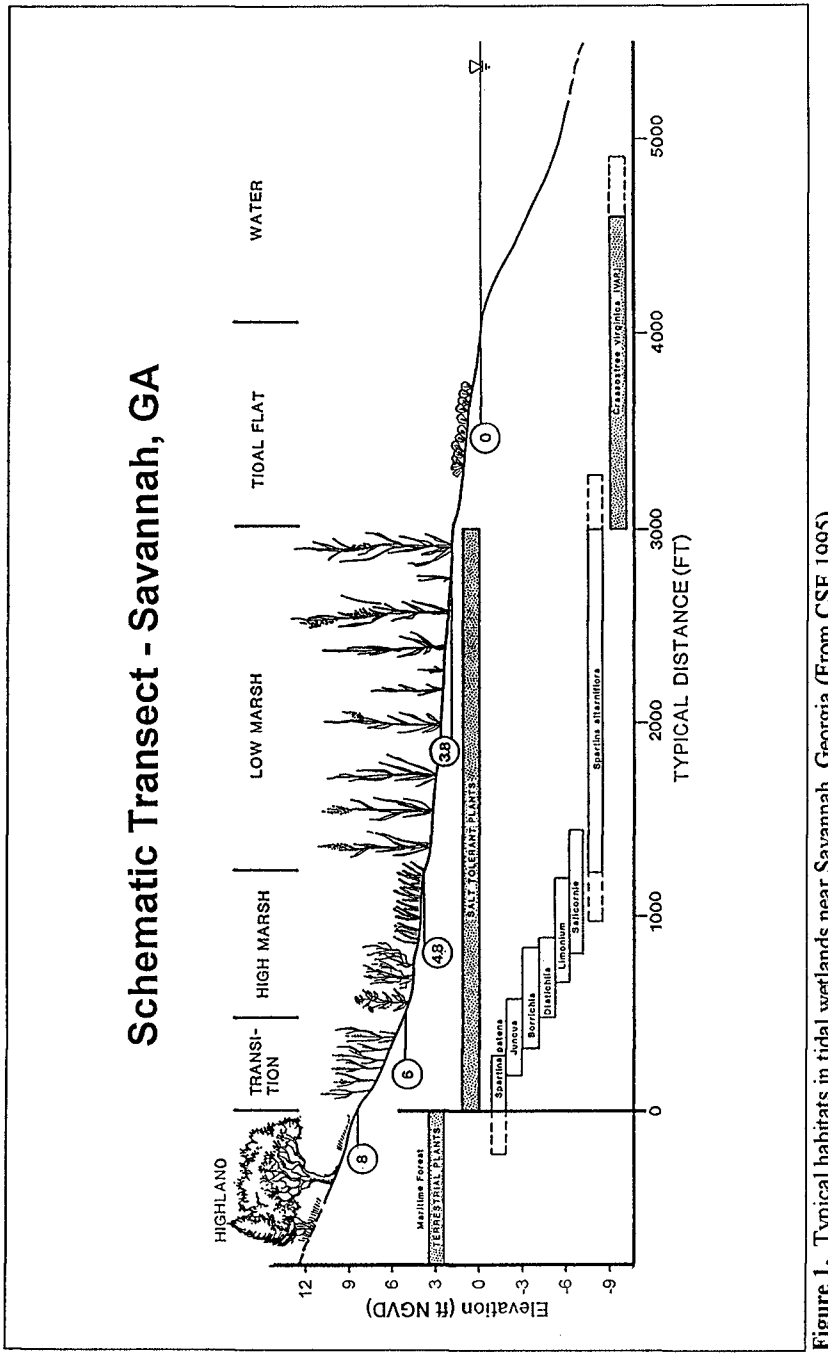


**Figure 1.** Typical habitats in tidal wetlands near Savannah, Georgia (From CSE 1995).

One method of delineation has been to identify habitats on the basis of flooding frequency – the number of times per day that an area is inundated. On the basis of flooding frequency, the basic habitats occur as follows (Kana et al., 1986):

| | |
|---|---|
| Highland | -- flooded rarely |
| Transitional wetlands | -- flooding ranges from biweekly to annually |
| High marsh | -- flooding ranges from daily to biweekly |
| Low marsh | -- flooded once or twice daily |
| Tidal flats | -- flooded up to half the day |
| Open water | -- flooded more than half the day |

Additionally, an often repeated rule of thumb has developed which states that low marsh exists where the substrate elevation is roughly at the mean high water level. However, the above criteria are too general to be incorporated into procedures for quantifying impacts on wetlands or to be used in wetland design criteria.

Many investigators (Adams, 1963 in Lagna, 1975; Kana et al., 1986) have extended the "mean high water" rule, saying that the primary factor controlling the distribution of wetland species is the relationship between marsh substrate elevation and local tidal water levels. Kana et al. (1986) even developed a normalized curve to be applied to arbitrary sites (Fig. 2). To use the normalized curve, a species-specific factor is read from the vertical axis and applied to the local extreme high water level referenced to mean sea level (MSL) datum. For example, for *Spartina alterniflora,* the water level factor is approximately 0.48. Therefore, at a site where extreme high water is 3 meters (m) MSL, *Spartina alterniflora* would be found in low energy environments with a substrate elevation of about 1.44 m MSL. Despite some findings that elevation alone does not control species distribution (Lagna, 1975), the appeal of such simple methods for engineering and environmental applications is clear.

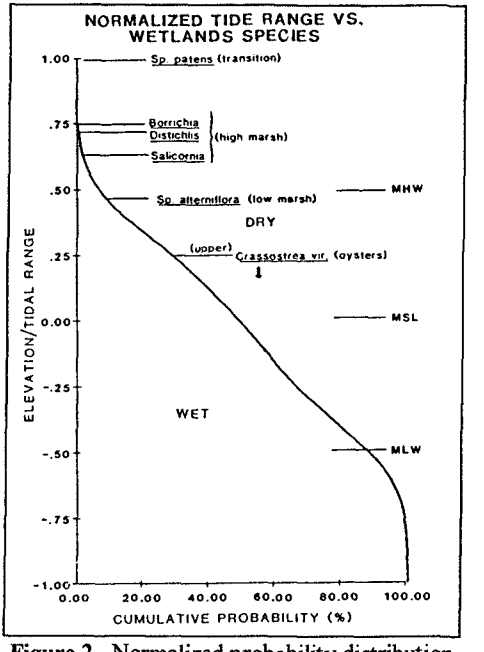


**Figure 2.** Normalized probability distribution of elevations for various wetland species (From Kana et al., 1986).

In this paper, the idea of hydraulic controls on tidal wetlands are refined and extended, and a general wetlands design method is proposed.

**Flooding Duration as a Control on Wetland Habitat Distribution**

It is generally accepted that character of inundation is the primary factor governing the distribution of wetland species. As described above, previous investigators have chosen to describe inundation in terms of substrate elevation relative to tidal water levels. However, relative elevation does not necessarily represent identical flooding characteristics at sites where tidal signature differs. For example, if two sites have equal tide ranges but one has an attenuated ebb tide, they will be flooded for differing periods for a given elevation (Fig. 3). When the effects of daily inequality, fortnightly cycles, and atmospherical affects are also introduced, relative elevation becomes an even less reliable measure of flooding character.

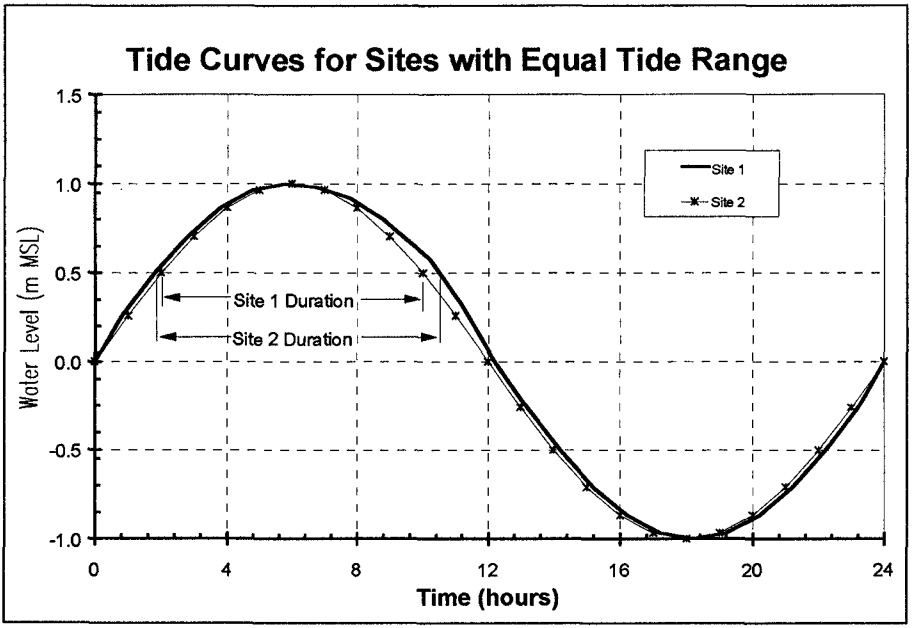


**Figure 3.** Flooding duration at equal elevations differ at sites where tidal signatures differ.

Flooding duration, the percentage of time that an area is inundated, is proposed as a more accurate measure of flooding character than relative elevation. Flooding duration is applied to species zonation in a manner similar to elevation.

It is assumed that wetland plant species are found in specific ranges of flooding duration. These ranges often overlap, and ranges for some species may be contained in the ranges of others. Indicator species may be chosen to identify specific wetland habitats. Wetland habitats are categorized by flooding duration in Table 1.

The durations listed in Table 1 are based on several wetlands surveys, the project described below, and many years of field observation. Nevertheless, minor variations should be expected on a site-specific basis. Until this method of design has gained wider acceptance, surveys of existing wetlands to confirm flooding durations for specific habitats should be conducted prior to design of new sites.

**Table 1.** Approximate flooding duration ranges for wetland habitats

| Habitat | Flooding Duration |
|---|---|
| Upland | 0 % |
| Transitional Wetlands | 0-2% |
| High Marsh | 2-5% |
| Low Marsh | 5-25% |
| Tidal Flats | 25-50% |
| Open Water | >50% |

Although somewhat cumbersome to use, flooding duration has several advantages over elevation, particularly when broadly applied:

1. The dominant factor controlling species zonation, the character of flooding, is more directly represented by flooding duration.
2. Flooding duration can be more generally applied than relative elevation since variations in tidal signature are accounted for.
3. The effects of frequent inundation due to storm surge or other factors are more accurately accounted for using flooding duration, particularly if a lengthy water level record is available. It is likely that this factor is particularly important where the tide range is relatively small and atmospherical events are more significant.
4. Flooding duration emphasizes the need for relatively long-term, site-specific water level measurements, while elevation data is easily misapplied to areas where the tide is attenuated or otherwise different from open-water conditions (commonly where tide gauges are located).

To calculate flooding duration, *a relatively long-term, site-specific water level record must be used* to account for daily inequality, fortnightly cycles, and irregular variations in water levels. Furthermore, existing tide gauges are generally located in open water where water levels are often significantly different than water levels in wetlands. To obtain an acceptable water level record, a tide gauge may need to be deployed.

The length of the record required will depend on local conditions affecting the variability of the water levels. Judgment must be used in determining the minimum length of record required at a particular site though, in most locations, a 25-day record will suffice.

Once an acceptable water level record is obtained, flooding duration for a given elevation is calculated as:

$$\textbf{Flooding Duration} = \frac{\textbf{Cumulative time with water level above elevation}}{\textbf{Total length of record}} \times 100$$

In some cases, the creation or alteration of a wetland has the potential to significantly change local water levels. This is undesirable since it has the potential to cause habitat transformations in existing wetlands. Additionally, specification of a substrate elevation corresponding to a desired flooding frequency becomes very difficult when postproject water levels are uncertain. Steps must be taken to minimize the impact of projects on local water levels. This can be accomplished by specifying an appropriate substrate elevation for the new wetland or by increasing the hydraulic capacity of connections to open water to accommodate increased flooding areas.

Numerical models can be extremely helpful in predicting postproject water levels when local hydraulics are altered by wetland creation.

## Sample Application: Mitigation Site Design

A recent CSE (1995) project involved hydraulic design for a 10-acre wetland at a site previously used for dredge spoil disposal near Savannah, Georgia. The site is approximately 900 m from the Savannah River and has hydraulic connection to the river via a complex network of ditches, culverts and existing wetlands (Fig. 4). The design objective was to create a tidal wetland at the site while minimizing both excavation requirements and impacts to existing wetlands.

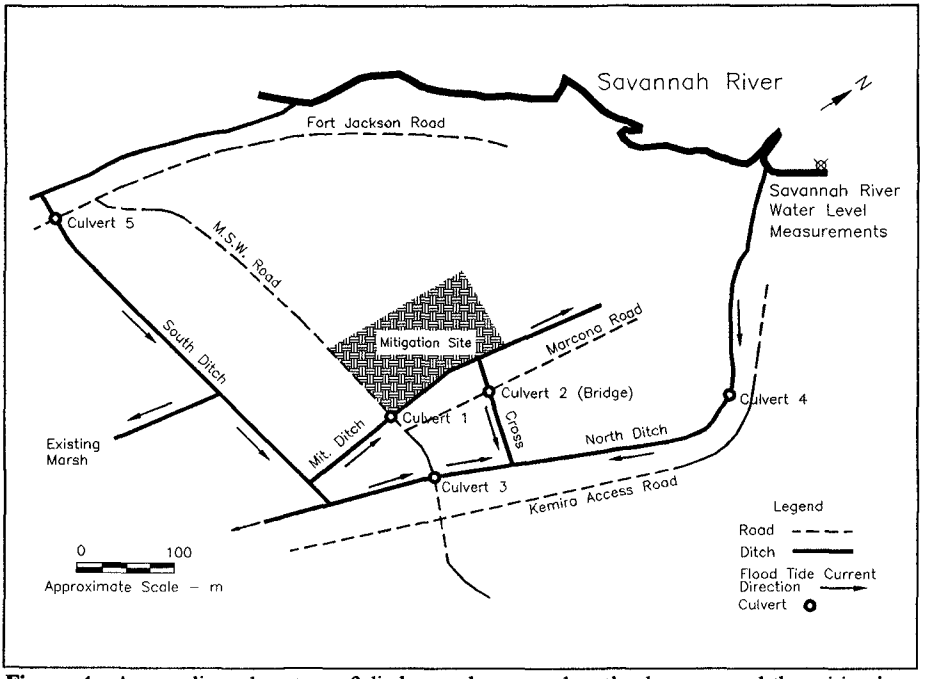


**Figure 4.** A complicated system of ditches, culverts, and wetlands connected the mitigation site to the Savannah River (From CSE, 1995).

The first step in applying the flooding duration method to the design was to determine the range of flooding duration for the type of wetland desired. A number of transects were surveyed through a nearby "natural" wetland. Elevation and distance were recorded at each point where species changed or where there were noticeable breaks in slope or elevation. Species types were identified with the assistance of a biologist. Elevation for each species was weighted by distance of occurrence to produce an elevation distribution for frequency of occurrence. The elevation data for all observed species were approximately normally distributed.

Local water level data were required to calculate flooding duration for the range of elevations observed for each species. Therefore, water level measurements in the surveyed wetland were taken over several tidal cycles and compared against data from a nearby permanent tide gauge. No significant water levels differences were observed between the surveyed marsh and the permanent gauge, so a 30-day record from the permanent gauge was used for flooding duration calculations. If significant differences had been noted between the marsh and gauge, water levels would have had to be measured at the site for a minimum of 25 days to provide adequate water level data for flooding duration calculations.

Flooding durations were calculated for the average elevation, and average elevation ± one standard deviation of each species observed (Table 2). Elevations outside this range are attributed to localized variations in water levels and errors introduced by weighting approximations. *Spartina alterniflora* was chosen as the low marsh indicator species, as is the usual practice on the East Coast. Therefore, the observed flooding duration range for local low marsh was found to be approximately 5 to 21 percent.

**Table 2.** Wetland species flooding durations near Savannah, Georgia (CSE, 1995).

| | Flooding Duration (% of tidal cycle) | | |
|---|---|---|---|
| Species | Mean | Lower Bound | Upper Bound |
| *Spartina cynocuroides* | 13.7 | 8.3 | 18.5 |
| *Spartina alterniflora* | 12.0 | 4.5 | 20.5 |
| *Carex* sp. | 9.3 | 2.7 | 19.9 |
| *Juncus* sp. | 6.3 | 3.2 | 11.3 |
| *Typha augustifolia* | 3.5 | 1.3 | 6.8 |

With the design flooding duration for low marsh established, the next step was to determine how to achieve this range at the mitigation site. The goal was to specify a substrate elevation range for the mitigation site which would result in the desired flooding frequency, given the hydraulic capacity of the ditch and culvert network. However, it was recognized that the addition of the 40,000 $m^2$ wetland to the existing system would change its tidal characteristics, making postproject water levels different than preproject levels. Without good estimates of postproject water levels, accurate determination of flooding duration was impossible. Furthermore, measurements of flows through existing channels and observations of flow restrictions

at culverts indicated that the existing system could not supply adequate tidal exchange to the mitigation site to sustain a low marsh. This meant that improvements would have to be made to the drainage system.

To gain some confidence in postproject conditions, DHI's Mike11 river model was used to simulate the ditch and wetland system. Figure 5 shows a schematic of the model setup. After calibration to existing conditions, the model proved instrumental in arriving at the final design by allowing the effects of ditch and culvert improvements, variation in mitigation site elevation, and impacts to existing wetland areas to be investigated.

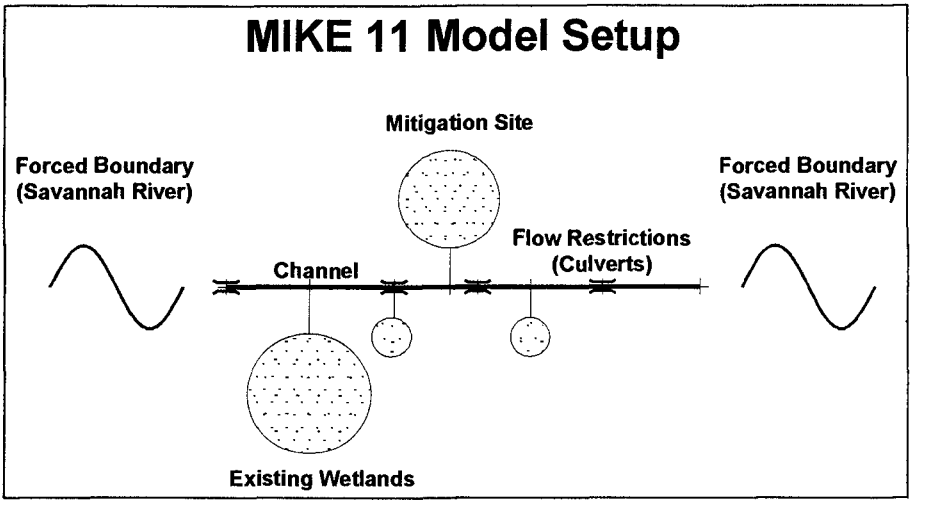


**Figure 5.** Schematic Mike11 model setup showing the channel/wetlands system modeled (From CSE, 1995).

Model results supported by field observations showed that both the existing wetlands and the site to be mitigated were flooded primarily by the south ditch (Fig. 4). This was primarily due to a topographic high point in the north ditch. With the high point and culvert 4 removed and the north ditch widened, the model showed that flooding of the mitigation site would occur from both the north and south. The model also showed significant increased flooding of the existing wetlands and the potential to convert them to "wetter" habitats. The final design recommendation was to isolate the mitigation site from the existing wetlands by closing culvert 1. Since the north ditch initially provided negligible flooding, the final design did not significantly impact existing wetlands.

With the hydraulic connection set, Mike11 was used to predict postproject water levels at the mitigation site. Using a simulated postproject water level record of 30 days, the variation in flooding duration at the mitigation with mitigation site elevation was established. Mike11 results for water levels at the mitigation site are shown in Figure 6, and corresponding volumetric flow rates in the improved north ditch are given in Figure 7.

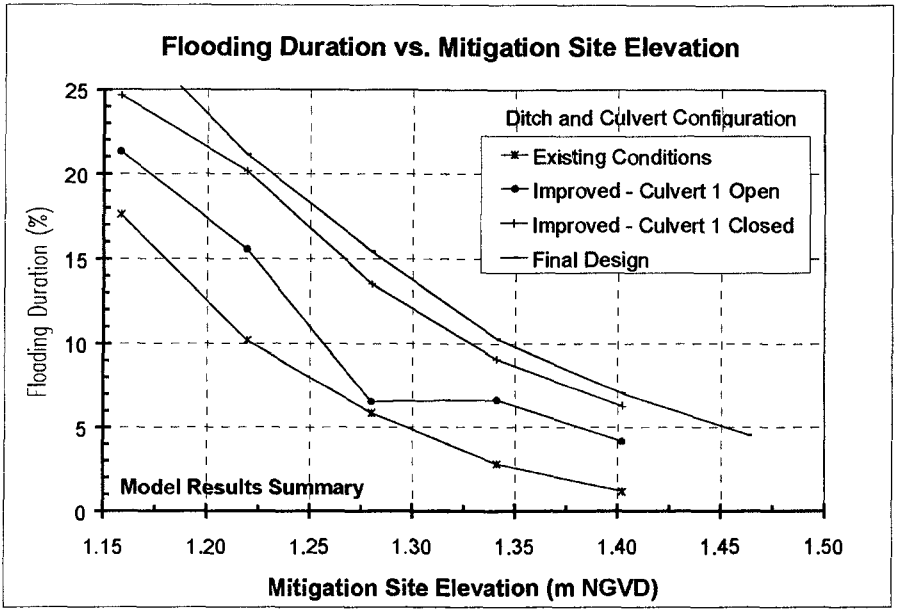


**Figure 6.** Mike11 model results. Flooding duration variation with mitigation site elevation and ditch/culvert configuration (From CSE, 1995).

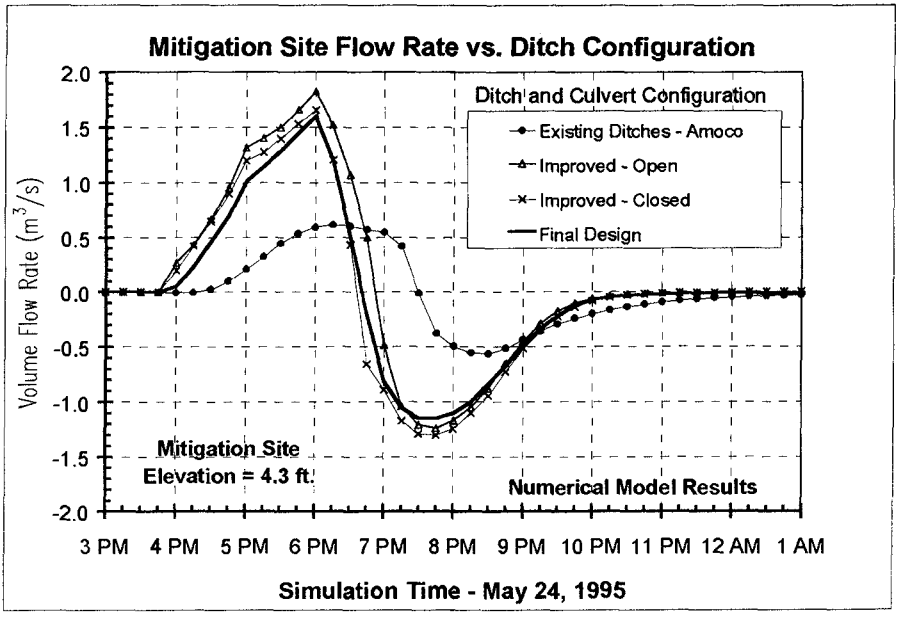


**Figure 7.** Mike11 model results. Volume flow rates to mitigation site for various ditch and culvert configurations (From CSE, 1995).

Despite the tidal attenuation, the mitigation site elevations were higher than those of the natural marsh. This was a result of greater attenuation of the ebb tide than the flood, which increased flooding duration at the site.

The final design for the mitigation site had the following dimensions:

| | |
|---|---|
| Wetland area to be created: | 40,000 $m^2$ |
| Wetland substrate elevation: | 1.22 m to 1.46 m NGVD |
| Wetland flooding duration: | 5 to 20 % |
| Length of ditch to Savannah R.: | 900 meters |
| Width of ditch: | 3 meters |
| River to wetland tide attenuation: | 0.03 to 0.15 meters |
| River to wetland phase lag: | 30-50 minutes |

## Conclusions

A procedure for the hydraulic design or improvement of tidal wetlands was proposed based on the principle that wetland plant species inhabit specific ranges of flooding duration. By creating areas with the appropriate flooding duration, desired habitats can be successfully created. When calculating flooding duration, relatively long-term site-specific water levels are required. A 30-day water level record is suggested for typical conditions. Where the creation of wetlands significantly alters local hydraulics, numerical models may be required to predict postproject water levels needed to determine wetland substrate elevations.

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