Appendix A
2002 Wetland Field Survey

WETLAND FIELD SURVEY

Purpose

That wetlands attenuate and mitigate the impacts of storm waters on other natural receiving waters is widely held. This functionality of wetlands was addressed as a basic element in assessing the value of Anchorage wetlands during re-adoption of the Anchorage Wetlands Management Plan in 1996. However, a quantitative or semi-quantitative analysis of the actual or potential performance of Anchorage wetlands in this regard was not done during the re-writing of the Plan.

The WMS is required to provide guidance in the design of facilities for the discharge of storm water to wetlands. Ultimately, WMS guidance will address three aspects of the discharge of storm water to wetlands: (a) suitability of a given wetland for receiving storm water, including identification of acceptable thresholds for physical, chemical and hydrologic impacts to the total wetland functionality; (b) performance of a wetland or portion of a wetland in treating chemical and physical impacts of storm water; and (c) performance of a wetland or portion of a wetland in treating hydraulic impacts of storm water.

Current WMS guidance is focused primarily, first, on identifying simple means of mitigating impacts of storm water on wetlands and, second, in providing planning-level tools for use in estimating the mitigation value of Anchorage wetlands on storm water hydraulic impacts. Guidance for identifying required mitigation activities and performance value in discharging storm water to wetlands is based on existing Anchorage wetlands management mapping, and application of new hydraulic analysis tools being developed by WMS. For this guidance, data required to identify mitigation thresholds is taken directly from the existing wetland classification scheme documented in the Anchorage Wetlands Management Plan and from updated wetlands mapping currently being completed by both the Planning and WMS departments of the Municipal Office of Planning, Development and Public Works (PD&PW). Data required for analysis of hydraulic impact and performance under this guidance is based in part on site-specific data and in part on categorical wetland values. The following summary describes the field data collected to determine the categorical wetland values to be used in the analytical tools as described under the general guidance. More detailed descriptions of WMS' wetland hydraulic model are included elsewhere.

Assessment Methodology

WMS assumes that the characteristics that are primarily responsible for a wetlands hydraulic response to storm water are generally reflected in the character of the wetland vegetation, at least at the resolution of the current WMS' model. Measuring ranges in values of important hydraulic characteristics for categories of wetland vegetation will therefore provide a means of rapidly identifying these hydraulic characteristics by simply mapping the vegetation type. This approach has value from two perspectives. First, hydraulic characteristics can be rapidly estimated using existing vegetation mapping or by using aerial photography to map vegetation communities. Second, because identification of vegetation communities is a critical element in classifying the overall functional value of wetlands at Anchorage, using vegetation in assessing hydraulic performance helps link this evaluation to the other functional evaluations.

Data Collection

In late summer of 2002 WMS consultants and staff collected data at 18 wetland sites (Figure 1) to obtain data for use in associating common vegetation communities to ranges in important hydraulic characteristics of Anchorage wetlands. Work included identification of those characteristics most important to the hydraulic performance of a wetland, and measurement of those characteristics within a broad range of wetland vegetation communities.

For the purpose of this analysis, Anchorage wetland vegetation communities were very broadly grouped and sampling sites assigned to one of these groups. The vegetation grouping for this study reflects the resolution applied in current guidance used for assessing mitigation of wetlands development at Anchorage (the Credit / Debit system). It also corresponds to the first level of the Alaska Vegetation Classification System (Viereck, et. al., 1992). Wetland groups used in this study include forested, shrub and herbaceous classes. Definitions for these groups were taken from Viereck and are generalized in Table 1.

Table 1 Vegetation Classification

Forested:	Wetlands with trees (over 3 meters tall) having a crown cover greater than 10%.
Shrub:	Wetlands with shrub cover greater than 25% or with at least 10% cover of dwarf trees (less than 3 meters tall).
Herbaceous:	Wetlands with predominant herbaceous vegetation cover and with no more than 25% shrub cover.

Sampling sites were assigned to these vegetation groups based on existing wetlands mapping and field and aerial photography assessment of vegetative cover within a sampling site. Although it was common for sampling sites to be bounded by wetland areas with other vegetative cover types, all sampled sites had a contiguous extent of common vegetation cover of at least 900 m^2.

Wetland characteristics were selected for measurement based on those hydraulic performance parameters identified as critical in development of a simple hydraulic routing model. Performance of a wetland in mitigating the hydraulic impacts of storm water discharges is primarily dependent upon the capability of the wetland to detain and delay release of peak storm water flows. These hydraulic performance capabilities will be strongly reflected in the physical characteristics of the wetland. Characteristics identified as critical included: soil pore space and small and large surface depressions that provide water storm storage, and wetland slope and vegetation type, height and extent that create resistance to flow. The hydraulic performance parameters measured as part of this assessment are described in more detail below.

Shallow soil characteristics were measured to help determine the soil water storage characteristics within different wetland categories. Shallow soils at all sites were sampled at one or more locations by probing with a coring tool to a minimum depth of 36 inches or to refusal. Soil cores were collected along the bottom of shallow depressions and do not represent the soil column in adjacent tussocks and mounds. In terms of hydraulic detention, this is assumed to result in conservative estimates as the mounds and tussocks are often comprised of more porous root masses. Soil cores were visually logged and classified according to the schema proposed by the Muskeg Subcommittee of the National Research Council of Canada (MacFarlane, 1969). The simplified classification and estimated associated characteristics used in this study are summarized in Table 2.

Table 2 Soils Classification

Soil Class	Description	Void Ratio, %	Permeability, cm/sec
Coarse Fibrous	Woody, coarse, fibrous peat	25%	10
Fine Fibrous	Woody fibrous peat in fine mineral soil	5%	10-3
Amorphous	Non-woody peat in fine mineral soil	3%	10-5

Location of the shallow ground water table and saturation of the sampled soil columns was also assessed.

Surface water storage is an important hydraulic element, particularly for wetland terrain where this type of storage can be large. In many of Anchorage wetland features, numerous micro-topographic depressions provide substantial surface storage. These small features are interconnected one to the next by a web of low ground sills that have elevations only slightly higher than their adjacent depressions. It is not until these micro-depressions have become filled with water and water spills across one or more of a depression's sills to the next down gradient depression, that general overland surface flow across the whole wetland occurs. For this study an estimate of the micro-topographic storage is derived from the field measurement of two variables, inter-depressional depth ('ID') and percent cover of the average inter-depressional storage depth ('ID%'). ID is defined as the mean difference in elevation between the bottom of micro-topographic depressions and the top of adjacent shallow sills that serve to interconnect adjacent depressions. In this study these depths were estimated by leveling rods horizontally over depressions within a site at the elevations of the surrounding sills and then measuring the depth from the leveled rod to the depression bottom. After 'ID' depths were determined, percent cover of this average storage depth (ID%) was visually estimated while walking several transects over the sample site.

During reconnaissance of a sample site, parameters representing resistance to surface water flow were also measured. These included the average height of low vegetation or ground cover (VegHt) and the percent of the flow plane that was obstructed by vegetation (%Obstruct). The height of ground cover vegetation, VegHt, is defined as the average height above the local sill elevation of the ground vegetation that presents continuous--100%--obstruction to flow (i.e., measured perpendicular to the fall line). The percentage of vegetation obstruction, %Obstruct, is defined as the average percentage of solid surface above VegHt that is presented perpendicular to the direction flow. Both these parameters were estimated by taken multiple measurements with a sample site.

Finally, the overall slope of the wetland sample site was measured. Slope is defined as the ratio of drop in elevation with horizontal distance, expressed as a percent (a 1 foot drop in 100 horizontal feet is a 1% slope). Slopes were estimated by measuring the elevation drop between sills using a hand level and a rod over a known horizontal distance of 100 or more feet. Slopes flatter than 0.5 percent could not be resolved using this technique and were given slope estimates of 0%.

Results

Sampling results at the 18 wetland sites are tabulated in Tables 3 and 4. Field data are summarized in Table 5 and 6.

Table 3 Wetland Field Soils Data

			Measured Strata Thickness (inches)				Water Level[b] (inches from surface)
Type	Site No.	Date	Coarse Fibrous	Fine Fibrous	Amorphous[a]	Mineral Soil	
Herbaceous	1	8/16/02	2	4	10		
Herbaceous	3	8/16/02	3	9	18		Surface
Herbaceous	10	8/20/02	0	20	20		Surface
Herbaceous	12	8/21/02	[c]	[c]	[c]	[c]	Surface
Herbaceous	14	8/21/02	0	15	7	8 (clay)	Surface
Herbaceous	16	8/21/02	0	20	20		Surface
Herbaceous	18	8/21/02	[c]	[c]	[c]	[c]	Surface
Shrub	5	8/16/02	4	4	28		
Shrub	7	8/20/02	0	24	16		Surface
Shrub	9	8/20/02	1	12	15		
Shrub	11	8/21/02	2	18	18		
Shrub	15	8/21/02	0	10	4	16 (clay)	
Forested	2	8/16/02	4	24	8		14
Forested	4	8/16/02	3	9	4		
Forested	6	8/20/02	3	10	23		
Forested	8	8/20/02	2	4	2		
Forested	13	8/21/02	2	2	4		
Forested	17	8/21/02	0	15	13		

Key:

a – Amorphous layer is assumed to continue to a depth greater than that measured unless a thickness was recorded for "Mineral Soil"

b – Soils were typically saturated above the water table

c – Representative soil bore could not be extracted

Table 4 2002 Wetland Field Survey Data

Type	Date	Site No.	ID	ID%	VegHt	%Obstruct	Slope
Herbaceous	8/16/02	1	4 in.	65%	36 in.	0%	0
Herbaceous	8/16/02	3	4 in.	50%	8 in.	5%	0.5%
Herbaceous	8/20/02	10	1 in.	80%	12 in.	<0.5%	<0.5%
Herbaceous	8/21/02	12	<1 in.	>90%	36 in.	0%	<0.5%
Herbaceous	8/21/02	14	<1 in.	>90%	30 in.	<5%	<0.5%
Herbaceous	8/21/02	16	<1 in.	>80%	36 in.	<10%	<0.5%
Herbaceous	8/21/02	18	<1 in.	>90%	18 in.	0%	<0.5%
Shrub	8/16/02	5	8 in.	50%	12 in.	<5%	0.5%
Shrub	8/20/02	7	12 in.	50%	36 in.	<5%	0.5%
Shrub	8/20/02	9	4 in.	60%	12 in.	<10%	<0.5%
Shrub	8/21/02	11	4 in.	50%	24 in.	0%	<0.5%
Shrub	8/21/02	15	4 in.	>80%	6 in.	0%	<0.5%
Forested	8/16/02	2	8 in.	60%	8 in.	15%	0
Forested	8/16/02	4	12 in.	40%	6 in.	40%	variable
Forested	8/20/02	6	8 in.	60%	12 in.	40%	<0.5%
Forested	8/20/02	8	6 in.	40%	12 in.	60%	1%
Forested	8/21/02	13	3 in.	60%	6 in.	25%	0.5%
Forested	8/21/02	17	8 in.	75%	12 in.	70%	

Table 5 2002 Field Soil Data Summary

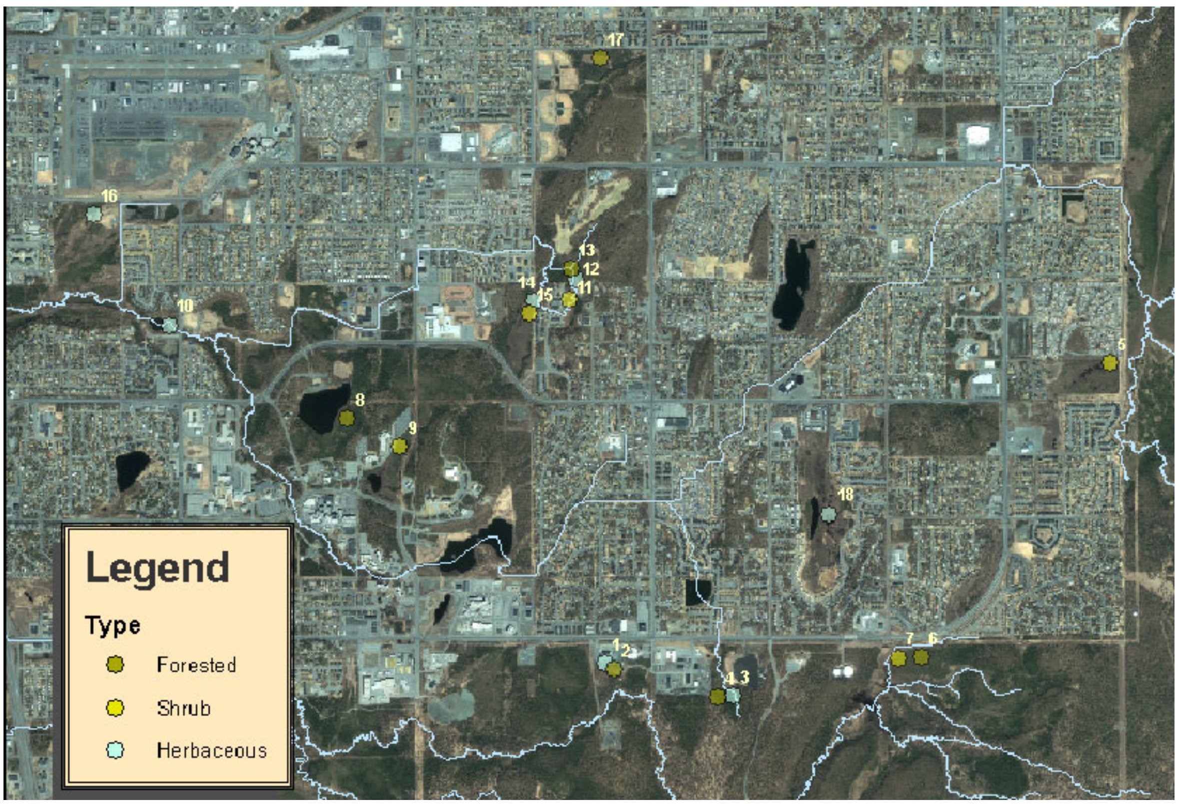
Type	Soil Range and Median (thickness in inches)					
	Coarse fibrous		Fine fibrous		Amorphous	
	Range	Median	Range	Median	Range	Median
Herbaceous*	0-3	0	4-20	15	7-20	18
Shrub	0-4	1	4-24	12	4-28	16
Forested	0-4	2.5	2-24	10	2-23	6

In general, soils at all sampling sites were saturated to the surface though position of the ground water table varied from site to site. These conditions are not unexpected for these landforms, where soil suction is strong and ground water is typically present throughout the year at shallow depths. In general, two important conclusions can be drawn from these data. First, little or no storm water storage capacity will be provided by soils in the herbaceous vegetation class because these soils are typically saturated to the surface. Second, given the relative permeabilities of the strata, only the surface coarse fibrous layer will provide any storm water storage capacity for the two other vegetation classes. Thus the overall thickness of the peat soils will generally be irrelevant to the short-term storm water storage capacity of wetland soils, with only the very near surface coarse peaty soils playing a role.

Table 6 2002 Field Survey Data Summary

Type	ID (inches)		ID%		VegHt (inches)		%Obstruct		Slope
	Range	Median	Range	Median	Range	Median	Range	Median	General
Herbaceous	1-4	1	50->90	80	8-36	30	0-10	0.5	<0.5%
Shrub	4-12	4	50->80	50	6-36	12	0-<10	5	<0.5%
Forested	3-12	8	40-75	60	6-12	10	15-70	40	0.5%

Depression storage and flow obstruction data show a fairly sharp distinction between the different wetland vegetation classes. Data for micro-depressions shows a large storage capacity available in ‘forested’ wetlands, with a somewhat more moderate capacity seen for the ‘shrub’ category. ‘Herbaceous’ wetlands appear to provide little micro-depression storage. Ground cover obstruction appears to be the same between the vegetation types, with herbaceous types surprisingly seeming to reflect the greatest degree of near-ground obstruction to flow. However, this data alone may not be representative of actual flow resistance effects. The predominant ground cover vegetation types for herbaceous wetlands is sedges and grasses while the forbs and low woody plants more typical of shrub-type wetlands may create much greater resistance to flow despite their somewhat lower profile. Obstructions may not be an important factor for herbaceous and shrub wetland types, but clearly are very important for a forested wetland. Considering the modest ground cover height for these wetland types, this factor may be important even for storm water flows where flows are not expected to reach substantial depths. Finally, the slope data collected for this study is biased for lowland wetland features and may not reflect a reasonable range in slopes particularly for the forested type. In fact, slope may not be predictable based on wetland vegetation type, except perhaps for the herbaceous category.



References for Appendix A

MacFarlane, Ivan C., editor. 1969. Muskeg Engineering Handbook. By the Muskeg Subcommittee of the NRC Associate Committee on Geotechnical Research. University of Toronto Press.

Viereck, L.A., C.T. Dyrness, A.R. Batten, and K.J. Wenzlick. 1992. The Alaska. Vegetation Classification. U.S. Department of Agriculture. Forest Service. Pacific Northwest Research Station. General Technical Report. PNW-GTR-286. July.

Appendix B
Wetlands Storm Routing Model

Model Overview

This model was developed to simulate the flow and storage of design storm events in wetlands. The model was not developed for long-term (greater than 3 days) wetland hydraulics or hydrology. Many of the assumptions are made for modeling large, discrete events and are not applicable to wetlands flow and storage on a day-to-day basis.

An inflow hydrograph is required for model operation. For use of this model, design rainfall events should be simulated over the wetland's tributary basin using Municipality of Anchorage (MOA) Design Criteria Manual hyetographs for design events. The outflow hydrograph from the tributary basin becomes the inflow hydrograph for the wetland model. Note that if the wetland has more than one point of inflow, this inflow is not currently included in the model. The inflow hydrograph is routed through the wetland to determine peak flow attenuation and wetland detention.

Wetland characteristics are also required for model operation. A wetland is described by a length, generally along the fall line, a width (alternatively, total area could be specified), and vegetation types. These data are used to determine specific wetland storage and wetland flow parameters. The model allocates the influent hydrograph first to wetland storage, then to overland flow. Overland flow is represented by Manning's equation over an effective area of wetland. Assumptions for this simulation and the basis of the four test scenarios are presented in the following sections.

Inflow Hydrographs

Inflow hydrographs for the 2-year 6-hour event and the 100-year event over the tributary basin, as prescribed in the MOA Design Criteria Manual, should be simulated in the EPA Storm Water Management Model (SWMM) or an equivalent storm water routing software to develop an storm water outflow hydrograph. A time step of 5 minutes is required, which is used to size the equivalent sedimentation basin.

Effective Area Assumptions

Since discharge into the wetland is assumed to be from a point source, it is assumed that there will be some areas that will not receive flow, known as dead zones. Areas that receive flow are considered part of the "effective area." A simple geometric shape was assumed to represent this, as shown in Figure B-1.

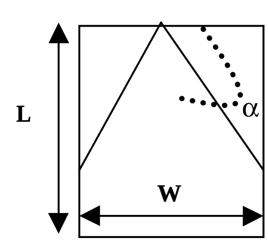


Figure B-1
Idealized Area

The angle α was approximated using correlations observed in shallow basins (Thackson et al., 1987). In that study of containment areas for dredged spoil material, mean residence times were measured in 12 basins. The ideal residence time, T, assumes plug flow, with no dead zones. However, when dead zones are present, the mean residence time is less than T, representing some short-circuiting of flow. The ratio of the measured residence time to the ideal detention time was computed for the 12 sampled basins. This ratio was correlated with the L/W ratio of the subject basins, resulting in the following equation:

$$\frac{\text{Mean residence time}}{\text{Computed residence time}} = 0.84\,[\,1 - \exp\,(-0.59 \times (L/W)\,]$$ (Thackston et al., 1987)

This correlation was found for data from shallow basins for which length, L, ranged from 450 to 3,010 feet; width, W, ranged from 140 to 1,350 feet; and L/W ranged from 1.4 to 4.1.

It was assumed that the mean detention time as a fraction of computed residence time can be used to represent the effective area as a fraction of the total area.

Therefore, the above equation can be rewritten as follows:

$$A_{eff} = 0.84\,[\,1 - \exp\,(-0.59\,(L/W)\,] \times A_{total}, \text{ where } A_{total} = L \times W$$

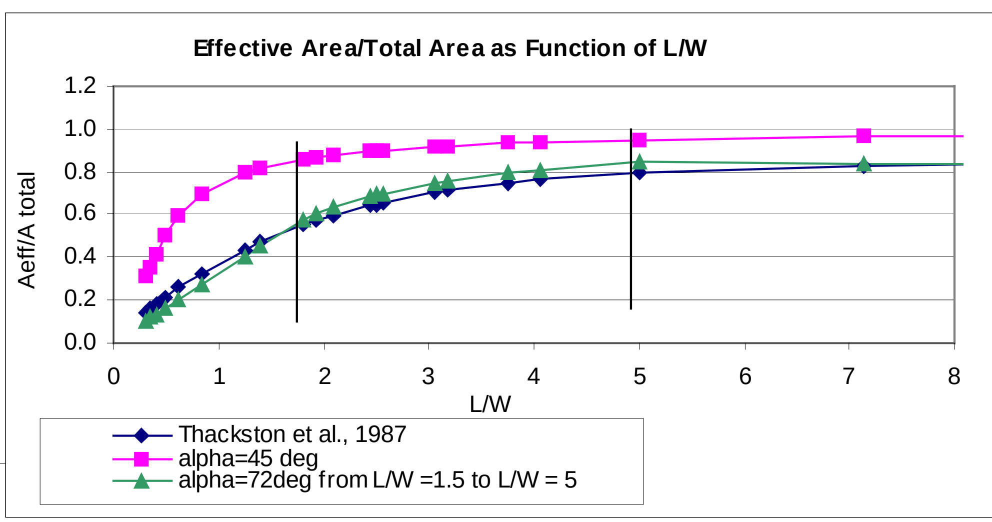
This equation was used to fit the trigonometric relationship shown in Figure B-2 below. The equation for effective area using the trigonometric approach is as follows:

$$A_{eff} = A_{total} - (\tan \propto) \times W^2/4, \qquad \text{when } L < W/2 \times (\tan \propto)$$

$$A_{eff} = L^2/(\tan \propto), \qquad \text{otherwise}$$

The relationship of the Thackston equation and the assumed trigonometric relationship is shown in Figure B-2. Figure B-2 also shows the relationship when $\propto$ is equal to 45 degrees.

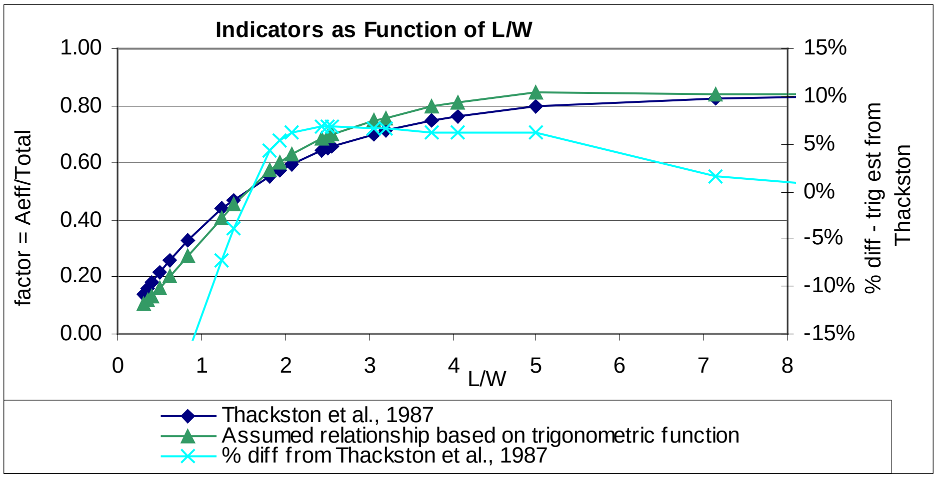
Figure B-2 Trigonometric Estimate of Effective Area



A good fit was found for α between 70 and 75 degrees and L/W less than 5. An angle of 72 degrees was selected. For L/W greater than 5, exp (-0.59 (L/W) approaches 0 and the ratio is 0.84, resulting in Aeff = 0.84 x Atotal.

When L/W is between 2 and 5, the trigonometric relationship overestimates the Thackston estimate by about 5 percent as shown in Figure B-3. In Figure B-3, the factor is the ratio of Aeff to Atotal. For L less than 1.5, the trigonometric relationship underestimates the area increasingly as L/W approaches 0. At L/W = 1, it underestimates the area by about 15 percent. Since L/W is not expected to be much less than 1 or greater than 4, the relationship based on tan 72 degrees was used. The percent error for different L/W ratios using this assumption is shown in Figure B-3.

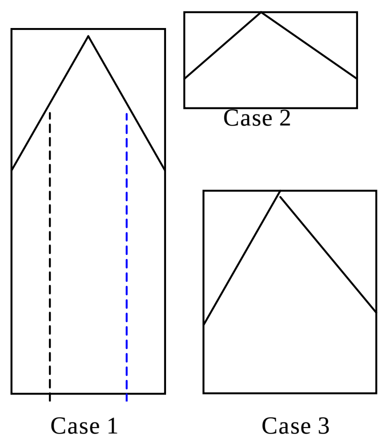
Figure B-3 Comparison of Error in Estimating Effective Area



Using the assumption of the geometric shape, effective area can be developed using the following steps. An illustration of the three cases is shown in Figure B-4.

- Determine the field measurements of L, W
- Compute L/W and A total (=L x W)
- If L/W is
  - >5, Aeff = 0.84 x L x W [Case 1]
  - < tan ∝/2, Aeff = L^2/(tan ∝) [Case 2]
  - otherwise, Aeff = A total – (tan ∝) x(W^2)/4 [Case 3]

Figure B-4 Three Wetland Geometry Cases



A trigonometric relationship was derived to spatially relate effective area to the actual wetland. This allows field investigations to concentrate on the assumed area of flow. Wetland parameters, such as vegetation type, intrinsic storage, and soil capacity, as used in the model, need only be specified for the effective area.

Effective width is computed as effective area divided by length to obtain the width of the flow path over which the flow is routed. Although actually triangular in shape, this flow area is approximated as a rectangle, following the methodology and assumptions of small error as documented for SWMM (Huber, 1988).

Parameters Associated with Wetland Types

Wetland parameters, such as soil capacity, slope, flow resistance (Manning's n), and intrinsic storage were found to be related to a wetland's vegetation types. Three vegetation types were identified for which distinct classes of these parameters. Individual parameters are described below and the values used for each of three wetland types are tabulated.

Wetland types include the following:

- Forest
- Shrub
- Herbaceous

These three wetland types are described in Appendix A, along with field data used to derive the specific parameters described below.

Wetland Storage

Wetland storage, termed intrinsic storage here, is the capacity of the wetland to retain water. It is assumed to be represented by soil capacity, interdepressional storage, and storage in ponds and open water.

Soil capacity represents the amount of water that can be held in the soil horizon. Interdepressional storage represents the capacity of the wetland to hold water between tussocks and small (less than 1 foot in diameter) localized mound features. Storage in ponds includes the capacity of the ponds to hold additional water over their steady-state levels, up to the level of the top of the interdepressional storage. This simple model required that intrinsic storage be filled before water was routed overland. This simplified approach ignores the time required for water to infiltrate into the soil and between hummocks. Each of the three components is described below.

SOIL CAPACITY

The soil's capacity for holding water is measured by the void ratio. Three soil horizons were identified: coarse fibrous, fine fibrous, and amorphous (Appendix A). The void ratio, expressed as the volume of voids divided volume of soil, was estimated for each horizon based on literature values.

Little or no storm water storage capacity will be provided by soils in the herbaceous vegetation class because these soils are typically saturated to the surface. Given the relative low permeabilities of the fine fibrous and amorphous strata, only the surface coarse fibrous layer will provide any storm water storage capacity for the two other vegetation classes. Thus the overall thickness of the peat soils will generally be irrelevant to the short-term storm water storage capacity of wetland soils, with only the very near surface coarse peaty soils playing a role.

The porosity value, used as soil capacity in this model, and thickness for each wetland type are shown in Table B-1.

Table B-1 Soil Depth and Porosity

	Vegetation Type		
	Forested	**Shrub**	**Herbaceous**
Soil Depth, feet	0.21	0.08	0.00
Assumed Soil Porosity (%)	0.44	0.44	0.00

The soil storage capacity is expressed in acre-feet as the following:

Vsc = Aeff (acres) x Soil Depth (feet) x Assumed Porosity

INTERDEPRESSIONAL STORAGE

Interdepressional storage is assumed to be present over some portion (fraction) of the areal extent of the wetland. The depth of this storage varies and a representative average depth is assumed. As described in Appendix A, the values listed in Table B-2 were derived and used for the wetland storm routing model.

Table B-2 Interdepressional Storage Values

Wetland Type	Interdepressional Storage Depth (feet)	Percent of Wetland Area (%)
Forested	0.67	60
Shrub	0.33	50
Herbaceous	0.08	80

The volume of interdepressional storage, expressed in acre-feet, is calculated as the following:

Vid = Aeff (acres) x Interdepressional Storage Depth (feet) x Percent of Wetland area

POND CAPACITY

Storage in ponds includes the capacity of the ponds to hold additional water over their steady-state levels, up to the level of the top of the interdepressional storage. No additional capacity was found in any of the ponds surveyed. This term is not currently used in the wetland model.

TOTAL INTRINSIC STORAGE

Total intrinsic storage for a wetland is the sum of the soil capacity and the interdepressional storage, if the wetland is a uniform vegetation type. Most wetlands have a mixture of vegetation type, so in these cases the intrinsic storage is computed for each vegetation type represented in the effective area, and then prorated for the fraction of the total area represented by the particular vegetation type.

Wetland Flow Routing

For overland flow, the Manning equation takes the following form:

$$Q = (1.49 / n) \times W \times d^{(5/3)} \times S^{(1/2)}$$

Where

Q is the flow in feet per second

n is the roughness coefficient (“Manning’s n”)

S is the slope in feet per feet

W is the effective width, in feet

d is the depth of water, in feet

Both slope and roughness were also assumed to be functions of wetland type. Width is taken as the effective width, or effective area divided by length, and depth is computed at each timestep of the model.

SLOPE

Most wetlands are fairly flat, so slopes are generally less than 1 percent. Because it is difficult to accurately measure slopes this flat, because slopes are not uniform, and because this is a driving factor in the Manning equation, the sensitivity of the model outcome to changes in slope was evaluated.

The effect of variations in slope on peak outflow, water depth, and storage volume are shown in Table B-3 and Figures B-5 and B-6. In these, a hypothetical hydrograph and all other wetland parameters are held constant. The table and figure illustrate that as slope decreases, storage volume increases and peak outflow decreases.

Table B-3 Sensitivity of Model Results to Assumed Slope

Assumed Slope	Peak Inflow (cfs)	Peak Outflow (cfs)	Maximum Depth (feet)	Maximum Storage (acre-feet)	Percent of Value when Slope is 0.5%: Peak Outflow	Maximum Depth	Maximum Storage
0.001%	83.1	0.52	0.136	12.6	-93%	36%	7%
0.01%	83.1	1.50	0.129	12.4	-78%	29%	5%
0.025%	83.1	2.25	0.125	12.3	-68%	25%	4%
0.05%	83.1	3.02	0.121	12.2	-57%	21%	4%
0.10%	83.1	3.90	0.115	12.1	-44%	14%	3%
0.20%	83.1	5.06	0.109	12.0	-27%	9%	2%
0.50%	83.1	6.97	0.100	11.8	0%	0%	0%
1%	83.1	8.69	0.093	11.6	25%	-7%	-1%
5%	83.1	13.35	0.074	11.2	92%	-26%	-5%
10%	83.1	15.12	0.065	11.0	117%	-35%	-6%
25%	83.1	17.30	0.054	10.8	148%	-47%	-9%
40%	83.1	18.26	0.048	10.6	162%	-52%	-10%

Key:
cfs – cubic feet per second

Figure B-5 Changes in Outflow, Water Depth, and Storage Volume with Changes in Slope

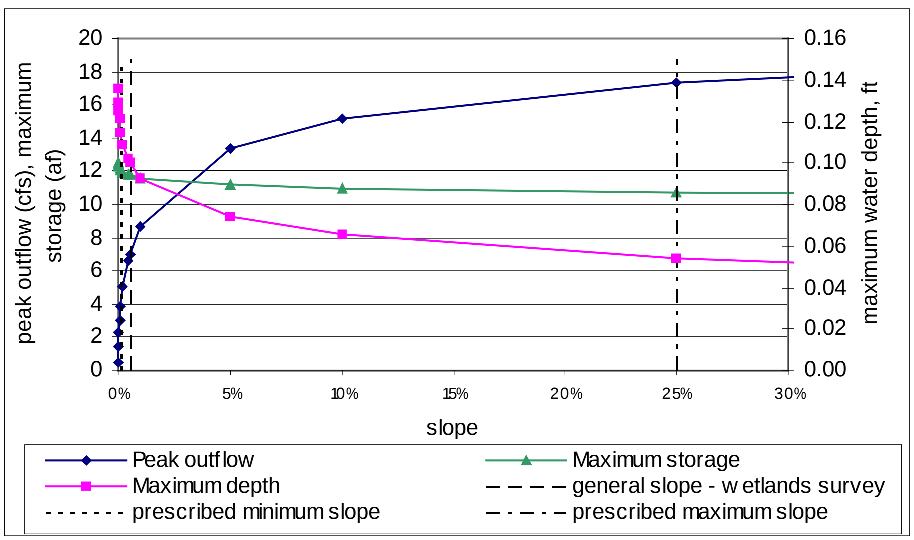
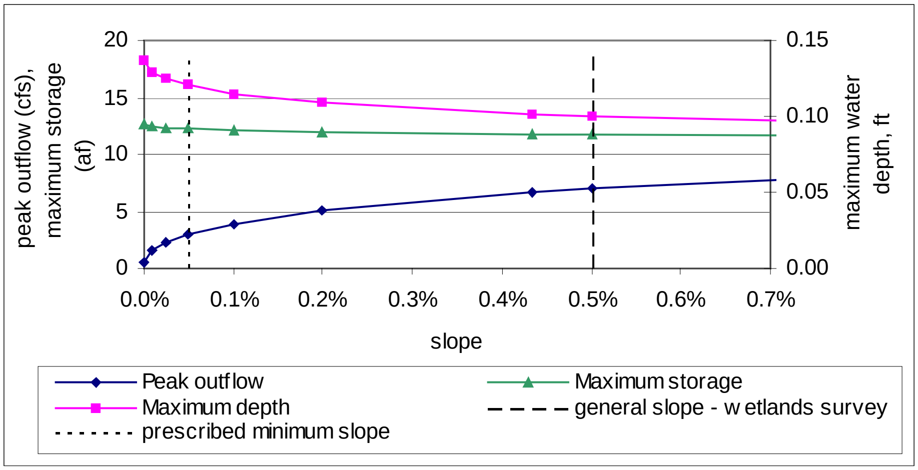


Figure B-6 Changes in Outflow, Water Depth, and Storage Volume with Changes in Shallow Slope



Literature suggests that hydraulics are very sensitive to this parameter. For slopes of less than 0.05 percent, increases and decreases are pronounced. This can be seen in Figure B-6 and is quantified in Table B-3. As slopes decrease below about 0.5 percent, flow decreases and water depth increases disproportionately. Above slopes of 10 to 25 percent, depending on groundcover, flowing water tends to become integrated and sheetflow is no longer a valid assumption.

For model input, the slope should be surveyed or calculated from topographic mapping. If the slope found is less than 0.05 percent, a minimum of 0.05 percent should be used in this model. Conversely, a slope no greater than 25 percent should be used If the wetland slope is greater than 25 percent or if it exhibits channel features along the fall line, this model is not appropriate.

ROUGHNESS VALUE ASSUMPTIONS

Another factor in the Manning equation dependent on wetland vegetation composition is the roughness coefficient. This is characterized by the following formula (Arcement, 1992):

n = (nb + b1 +n2 + n3 + n4) x m

Where

n is the channel n value

nb is a base value for n

n1 is correction factor for surface irregularities n2 is correction factor for variations in shape and size of channel cross section

n3 is correction factor for obstructions

n4 is correction factor for vegetation and flow conditions

m is correction factor from meandering of the channel

Since wetlands are more closely simulated as flood plains rather than flow channels, n2 and m are not applicable. Table B-4 presents the assumptions for the three wetland types that led to derivation of the selected n values.

Table B-4 Derivation of Manning's n for Different Wetland Types

[1]	General Description [1]	Qualifications for Choosing Range of Values for Inventoried Wetlands	Condition for Anchorage Wetlands	Range of Values for n_i [1] low	high	Value Selected
		Forested Wetlands				
n_b	Base roughness	All inventoried wetland types	Firm Soil	0.025	0.032	0.03
n_1	Irregularity	All inventoried wetland types	Moderate	0.006	0.01	0.008
n_3	Obstructions	Range 15-70%; median 40%	Appreciable	0.02	0.03	0.027
n_4	Vegetation	Median vegetation height 0.83 feet; greater than 2 times depth of flow	Very Large	0.05	0.10	0.083
		Calculated n for forested wetlands				**0.15**
		Shrub Wetlands				
n_b	Base roughness	All inventoried wetland types	Firm Soil	0.025	0.032	0.03
n_1	Irregularity	All inventoried wetland types	Moderate	0.006	0.01	0.008
n_3	Obstructions	Range 0-<10%; median 5%	Minor	0.005	0.019	0.01
n_4	Vegetation	Median vegetation height 1 foot; greater than 2 times depth of flow; dense willow	Extreme	0.1	0.2	0.15
		Calculated n for forested wetlands				**0.20**
		Herbaceous Wetlands				
n_b	Base roughness	All inventoried wetland types	Firm Soil	0.025	0.032	0.03
n_1	Irregularity	All inventoried wetland types	Moderate	0.006	0.01	0.008
n_3	Obstructions	Range 0-10%; median 0.5%	Negligible	0.000	0.004	0.002
n_4	Vegetation	Median vegetation height 2.5 feet; greater than 2 times depth of flow; dense willow	Extreme	0.1	0.2	0.15
		Calculated n for Herbaceous Wetlands				**0.19**

Key:
[1] Reference: Arcement, et al., 1992, Table 3 values for flood plain roughness

For wetlands that are made up of more than one vegetation type, the n value is computed for each type represented, then prorated for the fraction of the total area represented by a particular vegetation type to yield a composite n value.

Evaporation, Transpiration, and Infiltration

Evaporation and transpiration are important parts of the hydrologic cycle of wetlands. However, this analysis examined the routing of flood flows through a wetland from a 6-hour storm through a wetland. Response time was less than 30 hours, which would involve less than 2 days of evaporation. In addition to the short time step, high humidity associated with rainfall events would decrease the amount of evaporation. Finally, the rainfall falling on the wetland itself was not included in the routing. Therefore, the conservative case of rainfall matching evaporation over the wetland was assumed.

Infiltration of water through the wetland was also discounted in both the vertical and horizontal directions, primarily because response time of the wetland routing is short compared to the combined effect of the long flow length of the wetland and slow infiltration rates. For instance, permeability of peat is on the order of 0.04 cm / sec or less (MacFarlane, 1969), or less than 150 feet in 30 hours. Given a wetland length of over 1,000 feet, infiltrated water would not emerge from the wetland within the 30-hour response time.

Depth and Storage Computation

After intrinsic storage is filled, subsequent storm water inflow is routed through a wetland as overland flow. Overland flow routing, as characterized by Manning’s equation, computes both the depth and flow in the wetland for each time step. The methodology is patterned on that employed in the Storm Water Management Model (Huber, 1988), as described in Appendix V of that documentation and briefly described here.

Continuity requires that inflow must equal storage plus outflow. The change in volume of water with a change in time is characterized as the following:

$$dV / dt = A \times dd / dt = A \times I^* - Q$$

Where

V = A x d = volume of water in the on the effective area of the wetland (cubic feet)

d is water depth (feet)

t is time (seconds)

A is surface area of effective area (square feet)

I* is rainfall excess (feet / second) (inflow hydrograph divided by the effective area)

Q is outflow (cubic feet per second)

This is set equal to the outflow generated by the Manning's equation, as follows:

$$Q = W \times (1.49 / n) \times d^{(5/3)} \times S^{(1/2)}$$

Where

W = effective width (feet)

n = Manning's roughness coefficient

S = wetland slope

When these two equations are set equal to one another, the following equation is derived:

$$dd/dt = I^* - (1.49 \times W)/(A \times n) \times d^{(5/3)} \times S^{(1/2)}$$

This equation can be solved by approximation to yield a computed depth, d, at each time step. From the computed depth, flow is computed for the time step using the Manning equation and a resultant outflow hydrograph is generated.

References for Appendix B

Arcement, G.J. and V.R. Schneider. 1992. Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains. U.S. Geological Survey Water-Supply Paper 2339.

Huber, W.C., and R.E. Dickinson. 1988. Storm Water Management Model, Version 4: User's Manual. Cooperative Agreement CR-811607. Environmental Research Laboratory. Office of Research and Development. U.S. Environmental Protection Agency. August.

MacFarlane, Ivan C., editor. 1969. Muskeg Engineering Handbook. By the Muskeg Subcommittee of the NRC Associate Committee on Geotechnical Research. University of Toronto Press.

Peck, R.B, W.E. Hanson, and T.H. Thornburn. 1974. Foundation Engineering. John Wiley & Sons, Inc. New York.

Thackston, E.L., F.D. Shields, Jr., and P.R. Schroeder. 1987. Residence Time Distributions of Shallow Basins. ASCE Journal Of Environmental Engineering. Vol. 113, No. 6. December.

Appendix C
Sedimentation Basin Sizing and Cost Model

Sedimentation Pool Design Criteria

Criteria for designing sedimentation pools are included in the MOA Design Criteria Manual (DCM), Chapter 2 (MOA, 1986), and summarized in Table C-1.

Table C-1 Sedimentation Pool Design Criteria

	Portion of Pool		
Design Element	**Base**	**Active**	**Flood**
Surface area of base pool (A)	Peak inflow/(settling velocity of 20 µm particle x 0.85)	Not applicable	Not applicable
Side slopes	4:1	5:1	5:1
Volume	Sediment volume plus 5 feet depth	2-year 6-hour storm volume	100-year flood volume plus required freeboard
Depth	Minimum 5 feet; adjust upwards (8 feet maximum) to obtain cross-sectional area required for scour velocity limit	Using W,L projected from top of base pool, determine depth so that storm volume is contained	Using W,L projected from top of active pool, determine depth so that storm volume is contained; than add 1 foot freeboard
Width (W)	Square root of (A/5); adjust upwards to obtain cross-section area required for scour velocity limit	Project up from base pool based on required side slopes and computed depth	Project up from active pool based on required side slopes and computed depth
Scour velocity	0.04 feet per second Assume scour velocity limit can be met with combined area of base pool + active pool		
Length to width ratio	5 at top of base pool	Not applicable	Not applicable

The sediment pond sizing model requires the following input: the three peak 5-minute flow rates, in cubic feet per second, and the volume, in cubic feet, of the 2-year, 6-hour inflow and the 100-year 3-hour storm volume.

The sediment pond sizing algorithm proceeds as follows:

- A preliminary surface area for the base pool is estimated based on DCM criteria: area = peak inflow / (settling velocity of 20 µm particle x 0.85).
- Corresponding preliminary width and length are computed, based on preliminary surface area and prescribed L:W ratio.
- Preliminary volume for the base pool is computed based on the minimum depth, side slopes, and preliminary surface area.
- The depth of the active pool is estimated by solving for the depth of the active pool given the width and length based on projections from the base pool dimensions and the specified 2-year 6-hour volume. (A subroutine solves the cubic equation.)

- A check is made to determine if scour velocity is exceeded given the combined volumes and lengths of the preliminary base and active pools and the peak inflow rate. If scour velocity is exceeded, as it usually is, the pond size can be adjusted to meet this criterion by deepening either the base or active pools or by increasing the horizontal dimensions of the pond. In site-specific cases, one or more of these variables would be the constraint around which the others would be varied. For instance, site dimensions may limit the width of the pool; in that case, the depth or the length could be increased. For the generic case, the following method was used when scour velocity was exceeded:

  – A maximum base pool depth of 8 feet is assumed. The user may modify this; however, it should be no shallower than the DCM standard of 5 feet. The model computes the volume of sediment storage in the base pool for the user's information. A prescribed sediment volume is not part of the sizing criteria in this model.

  – The width and depth of the base pool are increased by 20 percent. If the increased depth exceeds the maximum base pool depth, the excess is added to the active pool depth. A new active pool depth is computed based on the new projected width and length of the base pool or the excess from the base pool calculation, whichever is greater. Scour velocity is again checked. A check is made that the active pool volume is adequate for the 2-year 6-hour storm.

  – If the geometry now satisfies the scour velocity by more than 5 percent (e.g., given scour velocity criteria of 0.04 ft/sec, computed velocity is less than 0.038 ft/sec), the dimensions of the depth and width of the active pool are decreased by 10 percent. A new active pool depth and volume are computed and the scour velocity checked again.

  – This iteration of increasing or decreasing size continues until a geometry that yields a scour velocity of between 0.038 and 0.04 ft/sec is found.

After the base and active pool geometries are determined, a surge pool is designed on top of the active pool to contain the excess of the 100-year storm volume over that of the 20-year storm plus 1 foot of freeboard. To develop a sedimentation pond "equivalent" to the wetland, only the fraction of the 100-year storm event volume that the wetland could store in intrinsic storage was included in the surge pool design volume. One foot of freeboard is added to the depth computed for flood storage. A minimum depth of 1.5 feet is prescribed if the computed depth of the surge pool is less than that.

Cost Estimate Assumptions

The following assumptions are made for estimating cost:

- The area to be cleared is 1.2 times the footprint of top of the flood pool
- Only the bottom 5 feet of base pool is dredged from native soil
- Berms are constructed from above the bottom 5 feet of the base pool to top of flood pool
- The berms have a 5:1 slope on the wet side and a 3:1 slope on the dry side
- Two-thirds of dredged material is unusable; the rest is used for landscaping
- The outlet weir is one quarter of the width of basin at the top of the flood pool and 15 feet deep
- A 15-foot strip on each side of the pond is seeded
- The area around the pond is landscaped with shrubs, trees, and groundcover
- Unit costs were taken from MOA Project Engineering and Management 2000 average bid prices

Maintenance Costs

Routine maintenance includes mowing, structural inspection, debris and litter removal, and erosion and nuisance control. Non-routine maintenance includes structural repairs and replacement and sediment removal on at 10- to 20-year cycle. The annual budget to cover routing and non-routine maintenance should be 3 to 5 percent of the base construction cost (Schueler, 1987).

The cost estimate does not include land acquisition costs. Sufficient land must be acquired for the following:

- The footprint, including the pond surface area and the entire lateral extent of the berms
- Access routes, that are a minimum of 10 feet in width
- Area for sediment disposal
- Buffer from surrounding properties

Maintenance costs can be reduced if land is acquired and set aside for sediment disposal.

Annualized Costs as a Function of Design Inflow

Annualized costs for construction are computed based on a 30-year life at 6 percent interest. Figures C-1 and C-2 show the effects of variable design storm parameters, peak inflow, and total volume on sediment basin geometry and cost. In these examples, the following are assumed:

- The 100-year storm volume is 126 percent of the 2-year storm volume
- The base pool depth must be between 5 and 8 feet
- The surge pool depth contains the incremental volume of the 100-year storm over the 2-year storm plus 1 foot of freeboard OR 1.5 feet, whichever is greater

Figure C-1 shows the effect of variable peak inflow, qpeak, on sedimentation pond geometry and cost, when storm volume is kept constant. This figure also shows the effect of increasing flow rates on the surface area of the pond. Since the sedimentation pond is designed to settle inorganic soil particles, scour velocity is a controlling factor. As peak inflow increases, the depth and/or width must increase to reduce the average flow velocity to prevent scour. This creates a pond with more volume than is required to contain the 2-year volume.

Figure C-1 Sediment Pond Parameters and Cost as Peak Inflow Velocity Varies

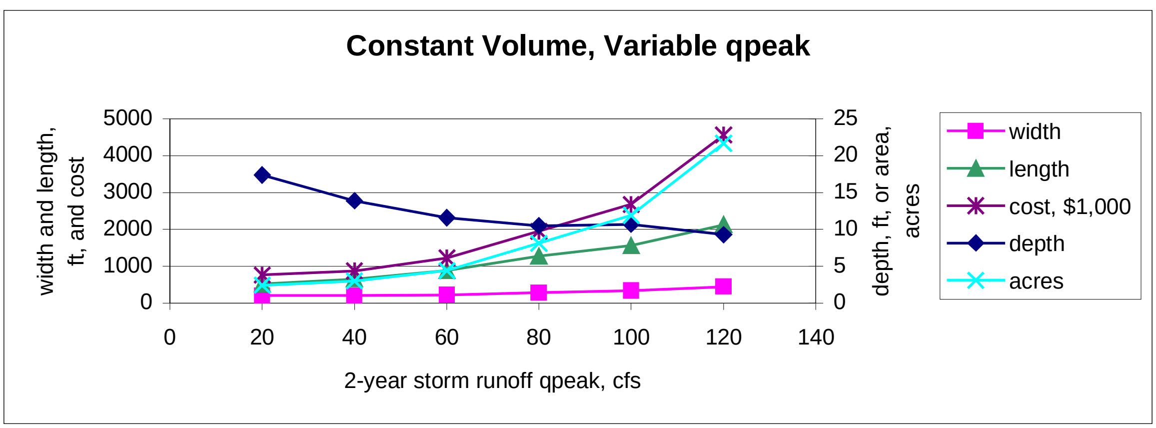


Figure C-2 Sediment Pond Parameters and Cost as Inflow Volume Varies

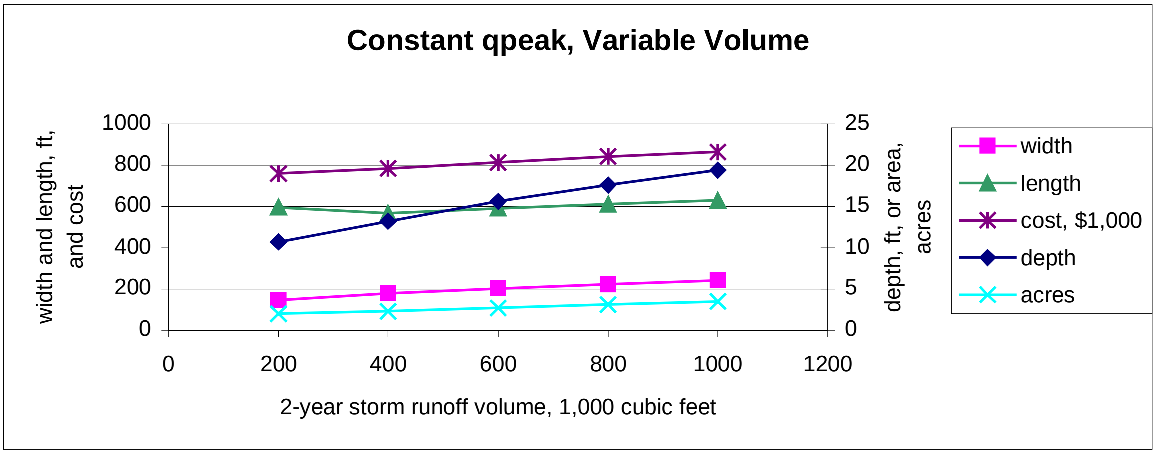


Figure C-2 shows the effect of increasing storm volume with a set peak flow rate. Because the peak flow rate was relatively low compared to the volume, scour velocity is generally satisfied by the required storage volume. The increase in width, depth, and length are proportional to increasing storage volumes.

Further refinement of sediment pond sizing to reduce cost could be achieved on a site-specific, based on characteristics of the inflow hydrograph and site conditions. However, this methodology was formulated to provide a generic case and costs that could be compared from one wetland scenario to another.

References for Appendix C

Schueler, Tom. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Department of Environmental Programs. Metropolitan Washington Council of Governments. Prepared for Washington Metropolitan Water Resources Planning Board. July.

Municipality of Anchorage. 1986. Design Criteria Manual.

MWH. 2002. Campbell Creek at Minnesota Drive Water Quality Enhancement Pond Upgrade. Design Study Report – Draft. Municipality of Anchorage Project Management and Engineering Department. June.

Appendix D
Example Model Output for Select Wetlands

Storm routing using the wetland model was conducted for four surveyed wetlands. The locations of the tributary basins and modeled wetlands are shown in Figure D-1.

Runoff hydrographs for the tributary basins were generated for two design storms for each wetland's tributary basin: the 2-year 6-hour storm and the 100-year 3-hour storm. These hydrographs were generated using the MOA SWMM model and the MOA Design Criteria Manual design storm hyetographs. The tributary basin areas and storm flow rates and volumes are shown in Table D-1.

Table D-1 Tributary Basins and Flows

Tributary Basin ID	Tributary Area (acres)	2-Year 6-Hour Storm 5-min peak inflow (cfs)	Volume (acre-feet)	100-Year 3-Hour Storm 5-min peak inflow (cfs)	Volume (acre-feet)
88	135	27.7	3.4	79.8	5.5
6	271	83.1	12.7	230.5	19.13
106	28	11.1	1.01	28	1.64
69	26	11.3	0.91	27.8	1.44

Key:
cfs – cubic feet per second
min – minute

Wetland model input for each of the four surveyed wetlands derived from the field survey is summarized in Table D-2.

Table D-2 Characteristics of Surveyed Wetlands

Field ID	Wetland Number	Wetland Description	Length (feet)	Width (feet)	Vegetation Type: Forest	Shrub	Herbaceous
					Fraction of Area		
7	251/267	North of Northern Lights and UAA	1,400	420	0.0	1	0
166	227	Merrill Field Wetlands	1,970	640	0.85	0.1	0.05
25	227	Merrill Field S of Chester Creek	540	350	0.5	0.5	0
119	227	Merrill Field E - Eastridge Condo Outfall	510	200	1.0	0.0	0

Model Results for Four Surveyed Wetlands

Computed values for the wetland storm routing are summarized in Table D-3.

Table D-3 Computed Values for Wetlands Routing

Tributary Basin ID	Field ID	Effective Area (acres)	Intrinsic Storage (acre-feet)	Storage Capacity as % of Storm Volume: 2 year storm (%)	Storage Capacity as % of Storm Volume: 100-year storm (%)	5-Min Peak Outflow: 2-year storm (cfs)	5-Min Peak Outflow: 100-year storm (cfs)
88	7	10.4	2.1	62	38	1.4	6.1
6	166	21.7	9.6	76	50	6.6	35
106	25	2.2	0.76	74	46	0.5	3.0
69	119	1.6	0.81	89	56	0.5	4.3

Key:
cfs – cubic feet per second

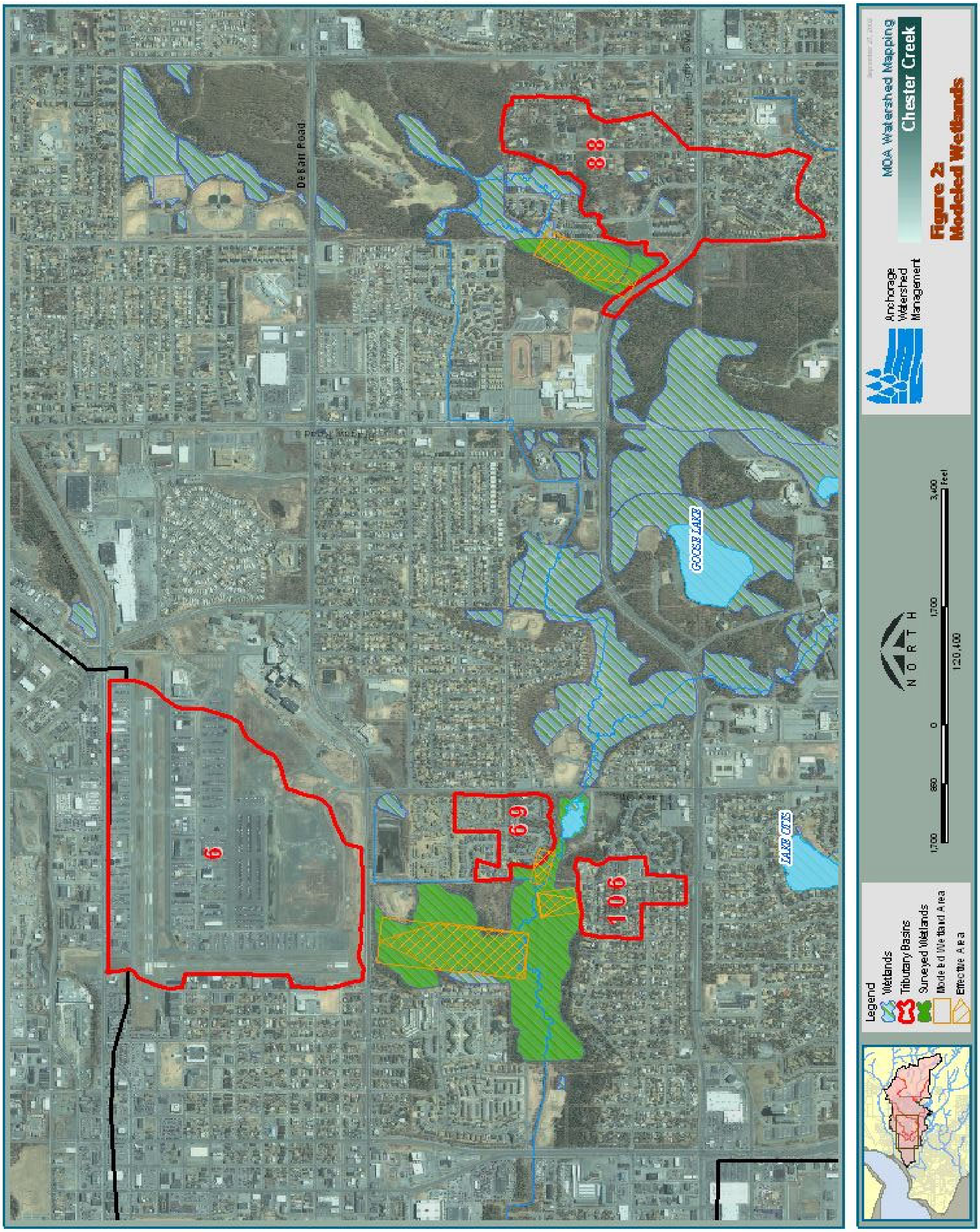
An equivalent sedimentation basin was sized based on the MOA Design Criteria Manual criteria for sedimentation basins, as described in Appendix C. The equivalent sedimentation basin included a flood control volume equal to that of the wetland; that is, it was not designed to contain the entire 100-year volume if the wetland did not contain a similar volume. Attributes of the equivalent sedimentation basin for each of the four modeled wetlands are summarized in Table D-4. Construction costs ranged from $499,000 to $1,980,000.

Table D-4 Characteristics of Equivalent Sedimentation Basin

Tributary Basin ID	Pond Surface Area (acres)	Pond Area as Percent of Tributary Basin (%)	Pond Area as Percent of Wetland Area (%)	Total Pond Volume (acre-feet)	Estimated Construction Cost (2002 $)
88	1.6	1.3	12	9.0	759,000
6	8.0	2.4	28	6.1	1,984,000
106	0.5	2.2	13	2.2	499,000
69	0.5	2.3	23	2.0	498,000

The wetland inflow and outflow hydrographs and equivalent sedimentation basin sizing and cost estimates for each wetland are included as attachments.

Figure D-1 Modeled Wetland Locations



Input Worksheet

BASIN ID	6	
BASIN Description	Merrill Field Wetlands	
FID	166	
Wetland ID	227	
Tributary area	271	ac
reach length	1970	ft
width	640	ft
slope along fall line	0.433%	ft/ft

% Wetland Type

Forested	0.85
Shrub	0.1
Herbaceous	0.05

cumulative time hrs	2-yr 6-hour inflow cfs	100-yr 3hr inflow cfs
0.1	0.027	0.232
0.2	0.078	1.314
0.3	0.138	3.954
0.3	0.21	6.742
0.4	0.438	10.32
0.5	0.722	14.602
0.6	1.127	19.079
0.7	1.65	23.381
0.8	2.341	28.825
0.8	2.99	34.903
0.9	3.592	40.602
1.0	4.301	45.704
1.1	5.339	50.12
1.2	6.513	53.597
1.3	7.737	56.248
1.3	8.943	58.828
1.4	10.086	72.2
1.5	11.144	130.1
1.6	12.105	208.4
1.7	12.968	230.5
1.8	14.287	188.5
1.8	16.016	146.5
1.9	17.833	118.6
2.0	19.567	100.9
2.1	21.122	89.5
2.2	22.457	81.6
2.3	23.567	75.8
2.3	24.472	71.7
2.4	25.199	68.7
2.5	26.027	66.6
2.6	26.977	65.1
2.7	27.805	64.0
2.8	28.495	62.9
2.8	29.059	61.7
2.9	37.018	60.6
3.0	63.448	59.9
3.1	83.116	54.3
3.2	78.126	43.1
3.3	67.515	33.9
3.3	58.435	26.9
3.4	51.601	21.7
3.5	46.59	17.7
3.6	42.915	14.6
3.7	39.941	12.2
3.8	37.36	10.3
3.8	35.35	8.8
3.9	33.795	7.5
4.0	32.591	6.5
4.1	31.654	5.6
4.2	30.923	4.9
4.3	30.35	4.2
4.3	29.899	3.7
4.4	29.296	3.3
4.5	28.509	2.9
4.6	27.824	2.5
4.7	27.255	2.2

4.8	26.79	2.0
4.8	26.413	1.8
4.9	26.109	1.6
5.0	25.865	1.4
5.1	25.428	1.2
5.2	24.791	1.1
5.3	24.221	1.0
5.3	23.739	0.9
5.4	23.106	0.8
5.5	22.317	0.7
5.6	21.396	0.7
5.7	20.366	0.6
5.8	19.471	0.5
5.8	18.718	0.5
5.9	18.092	0.4
6.0	17.573	0.4
6.1	16.099	0.4
6.2	13.794	0.3
6.3	11.737	0.3
6.3	10.005	0.3
6.4	8.564	0.2
6.5	7.363	0.2
6.6	6.36	0.2
6.7	5.517	0.2
6.8	4.805	0.1
6.8	4.199	0.1
6.9	3.68	0.1
7.0	3.234	0.1
7.1	2.849	0.1
7.2	2.514	0.1
7.3	2.222	0.0
7.3	1.966	0.0
7.4	1.741	0.0
7.5	1.544	0.0
7.6	1.369	0.0
7.7	1.216	0.0
7.8	1.08	0.0
7.8	0.96	0.0
7.9	0.855	0.0
8.0	0.764	0.0
8.1	0.683	0.0
8.2	0.613	0.0
8.3	0.552	0.0
8.3	0.498	0.0
8.4	0.449	0.0
8.5	0.405	0.0
8.6	0.364	0.0
8.7	0.327	0.0
8.8	0.293	0.0
8.8	0.262	0.0
8.9	0.233	0.0
9.0	0.206	0.0
9.1	0.182	0.0
9.2	0.159	0.0
9.3	0.139	0.0
9.3	0.12	0.0
9.4	0.103	0.0
9.5	0.087	0.0
9.6	0.073	0.0
9.7	0.06	0.0
9.8	0.048	0.0
9.8	0.038	0.0
9.9	0.029	0.0
10.0	0.021	0.0
10.1	0.015	0.0
10.2	0.01	0.0
10.3	0.005	0.0
10.3	0.002	0.0
10.4	0.001	0.0
10.5	0	0.0
10.6	0	0.0

Input Worksheet

BASIN ID	69	
BASIN Description	Merrill Field E - Eastridge condo outfall	
FID	119	
Wetland ID	227	
Tributary area	26 ac	ac
reach length	510	ft
width	200	ft
slope along fall line	1%	ft/ft

% Wetland Type	
Forested	1
Shrub	0
Herbaceous	0

cumulative time hrs	2-yr 6-hour inflow cfs	100-yr 3hr inflow cfs
0.1	0	0
0.2	0	0.317
0.3	0	0.778
0.3	0.009	1.061
0.4	0.082	1.818
0.5	0.164	2.372
0.6	0.246	2.576
0.7	0.303	2.633
0.8	0.36	2.648
0.8	0.397	2.651
0.9	0.448	2.785
1.0	0.606	3.219
1.1	0.794	3.776
1.2	0.946	4.209
1.3	1.029	4.501
1.3	1.067	4.768
1.4	1.082	6.5
1.5	1.088	14.9
1.6	1.09	27.8
1.7	1.091	22.0
1.8	1.123	11.2
1.8	1.179	7.6
1.9	1.21	6.2
2.0	1.224	5.6
2.1	1.23	5.3
2.2	1.232	5.1
2.3	1.233	4.9
2.3	1.233	4.8
2.4	1.257	4.8
2.5	1.386	4.8
2.6	1.602	4.7
2.7	1.806	4.7
2.8	1.972	4.7
2.8	2.099	4.6
2.9	3.226	4.5
3.0	7.747	4.5
3.1	11.312	3.8
3.2	6.3	2.1
3.3	4.225	1.2
3.3	3.365	0.8
3.4	2.953	0.5
3.5	2.732	0.4
3.6	2.605	0.3

3.7	2.492	0.2
3.8	2.354	0.1
3.8	2.27	0.1
3.9	2.221	0.1
4.0	2.192	0.0
4.1	2.174	0.0
4.2	2.163	0.0
4.3	2.156	0.0
4.3	2.152	0.0
4.4	2.112	0.0
4.5	2.025	0.0
4.6	1.969	0.0
4.7	1.937	0.0
4.8	1.919	0.0
4.8	1.908	0.0
4.9	1.901	0.0
5.0	1.897	0.0
5.1	1.858	0.0
5.2	1.774	0.0
5.3	1.719	0.0
5.3	1.686	0.0
5.4	1.632	0.0
5.5	1.542	0.0
5.6	1.447	0.0
5.7	1.335	0.0
5.8	1.259	0.0
5.8	1.212	0.0
5.9	1.181	0.0
6.0	1.162	0.0
6.1	0.99	0.0
6.2	0.684	0.0
6.3	0.467	0.0
6.3	0.324	0.0
6.4	0.228	0.0
6.5	0.161	0.0
6.6	0.114	0.0
6.7	0.08	0.0
6.8	0.056	0.0
6.8	0.039	0.0
6.9	0.026	0.0
7.0	0.018	0.0
7.1	0.012	0.0
7.2	0.008	0.0
7.3	0.005	0.0
7.3	0.003	0.0
7.4	0.001	0.0
7.5	0	0.0
7.6	0	0.0

Input Worksheet

BASIN ID	88	
BASIN Description	North of N Lts at UAA	
FID	7	
Wetland ID	251/267	
Tributary area	135 ac	ac
reach length	1400	ft
width	420	ft
slope along fall line	0.05%	ft/ft

% Wetland Type

Forested	0
Shrub	1
Herbaceous	0

cumulative time hrs	2-yr 6-hour inflow cfs	100-yr 3hr inflow cfs
0.1	0.004	0.031
0.2	0.01	1.217
0.3	0.017	3.051
0.3	0.023	4.18
0.4	0.164	5.221
0.5	0.453	5.959
0.6	0.821	6.369
0.7	1.115	6.562
0.8	1.433	6.644
0.8	1.636	6.706
0.9	1.77	7.415
1.0	1.918	8.984
1.1	2.199	10.9
1.2	2.413	12.801
1.3	2.558	14.468
1.3	2.646	16.238
1.4	2.697	25.0
1.5	2.725	55.1
1.6	2.74	79.8
1.7	2.748	72.6
1.8	2.896	52.6
1.8	2.993	39.5
1.9	3.049	32.0
2.0	3.081	27.6
2.1	3.097	25.0
2.2	3.106	23.0
2.3	3.111	21.7
2.3	3.246	20.8
2.4	3.562	20.2
2.5	4.18	19.7
2.6	4.88	19.4
2.7	5.59	19.3
2.8	6.259	18.9
2.8	6.855	18.6
2.9	12.6	18.3
3.0	25.899	18.2
3.1	27.666	14.4
3.2	23.021	10.6
3.3	18.842	7.8
3.3	16.01	5.9
3.4	14.122	4.5
3.5	12.838	3.5
3.6	11.942	2.8

3.7	11.112	2.2
3.8	10.458	1.8
3.8	9.964	1.4
3.9	9.597	1.2
4.0	9.323	0.9
4.1	9.118	0.8
4.2	8.963	0.6
4.3	8.847	0.5
4.3	8.758	0.4
4.4	8.506	0.3
4.5	8.272	0.2
4.6	8.081	0.2
4.7	7.934	0.1
4.8	7.821	0.1
4.8	7.735	0.1
4.9	7.67	0.0
5.0	7.62	0.0
5.1	7.402	0.0
5.2	7.197	0.0
5.3	7.027	0.0
5.3	6.893	0.0
5.4	6.615	0.0
5.5	6.366	0.0
5.6	5.991	0.0
5.7	5.666	0.0
5.8	5.403	0.0
5.8	5.194	0.0
5.9	5.028	0.0
6.0	4.898	0.0
6.1	4.004	0.0
6.2	3.216	0.0
6.3	2.58	0.0
6.3	2.077	0.0
6.4	1.679	0.0
6.5	1.361	0.0
6.6	1.106	0.0
6.7	0.898	0.0
6.8	0.728	0.0
6.8	0.588	0.0
6.9	0.472	0.0
7.0	0.376	0.0
7.1	0.296	0.0
7.2	0.23	0.0
7.3	0.175	0.0
7.3	0.13	0.0
7.4	0.094	0.0
7.5	0.065	0.0
7.6	0.043	0.0
7.7	0.028	0.0
7.8	0.016	0.0
7.8	0.008	0.0
7.9	0.003	0.0
8.0	0	0.0
8.1	0	0.0
8.2	0	0.0
8.3	0	0.0

Input Worksheet

BASIN ID	106	
BASIN Description	Merrill Field S of Chester Ck	
FID	25	
Wetland ID	227	
Tributary area	28	ac
reach length	540	ft
width	350	ft
slope along fall line	0.2640%	ft/ft

% Wetland Type	
Forested	0.5
Shrub	0.5
Herbaceous	0

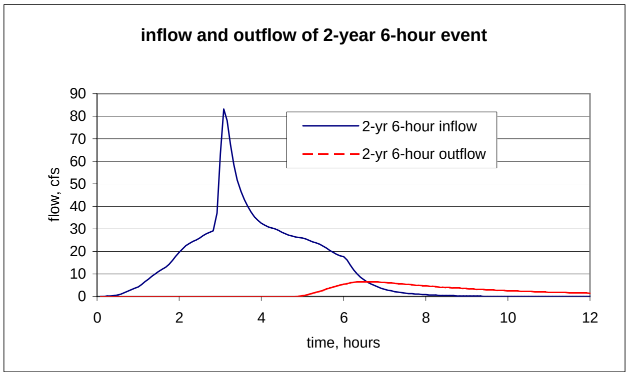
cumulative time hrs	2-yr 6-hour inflow cfs	100-yr 3hr inflow cfs
0.1	0	0
0.2	0	0.283
0.3	0	0.715
0.3	0.002	0.981
0.4	0.062	1.508
0.5	0.141	1.988
0.6	0.224	2.228
0.7	0.282	2.319
0.8	0.342	2.35
0.8	0.379	2.361
0.9	0.416	2.614
1.0	0.516	3.142
1.1	0.662	3.787
1.2	0.795	4.353
1.3	0.882	4.789
1.3	0.929	5.19
1.4	0.953	7.1
1.5	0.964	15.2
1.6	0.968	28.0
1.7	0.971	25.0
1.8	1.003	15.0
1.8	1.045	10.5
1.9	1.072	8.3
2.0	1.087	7.3
2.1	1.093	6.7
2.2	1.096	6.3
2.3	1.098	6.0
2.3	1.124	5.8
2.4	1.224	5.7
2.5	1.411	5.6
2.6	1.655	5.6
2.7	1.889	5.5
2.8	2.09	5.5
2.8	2.253	5.4
2.9	3.444	5.3
3.0	7.577	5.3
3.1	11.053	4.5
3.2	7.561	2.9
3.3	5.497	1.9
3.3	4.438	1.4
3.4	3.846	1.0
3.5	3.49	0.7
3.6	3.264	0.5
3.7	3.076	0.4
3.8	2.894	0.3
3.8	2.766	0.2
3.9	2.68	0.2

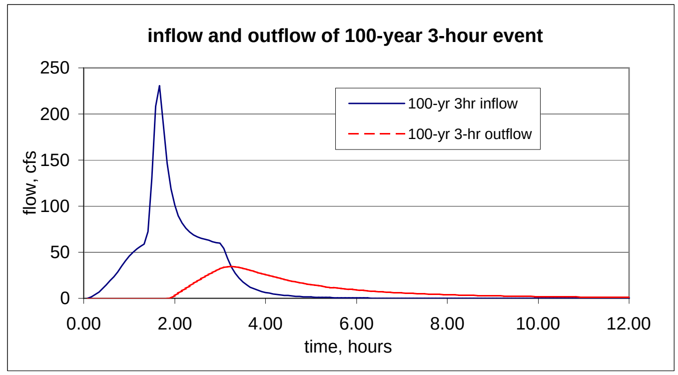
4.0	2.621	0.1
4.1	2.581	0.1
4.2	2.553	0.1
4.3	2.533	0.1
4.3	2.518	0.0
4.4	2.47	0.0
4.5	2.387	0.0
4.6	2.324	0.0
4.7	2.281	0.0
4.8	2.252	0.0
4.8	2.233	0.0
4.9	2.219	0.0
5.0	2.21	0.0
5.1	2.166	0.0
5.2	2.088	0.0
5.3	2.028	0.0
5.3	1.986	0.0
5.4	1.921	0.0
5.5	1.832	0.0
5.6	1.727	0.0
5.7	1.613	0.0
5.8	1.525	0.0
5.8	1.462	0.0
5.9	1.417	0.0
6.0	1.384	0.0
6.1	1.194	0.0
6.2	0.903	0.0
6.3	0.674	0.0
6.3	0.507	0.0
6.4	0.385	0.0
6.5	0.294	0.0
6.6	0.225	0.0
6.7	0.172	0.0
6.8	0.131	0.0
6.8	0.099	0.0
6.9	0.073	0.0
7.0	0.054	0.0
7.1	0.039	0.0
7.2	0.027	0.0
7.3	0.018	0.0
7.3	0.012	0.0
7.4	0.008	0.0
7.5	0.005	0.0
7.6	0.003	0.0
7.7	0.001	0.0
7.8	0	0.0
7.8	0	0.0
7.9	0	0.0
8.0	0	0.0
8.1	0	0.0

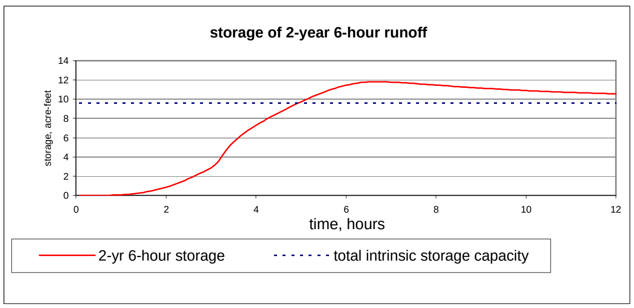
WETLANDS STORM ROUTING

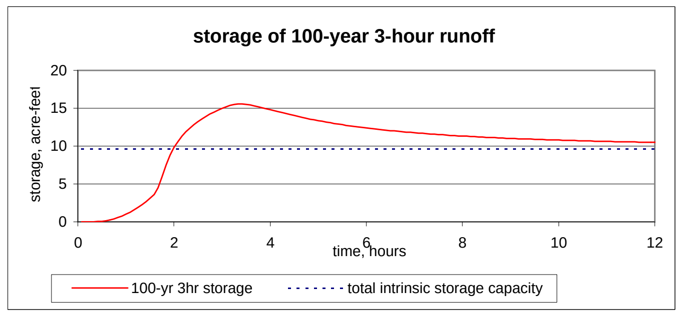
BASIN ID	6
BASIN Description	Merrill Field Wetlands
FID	166
Wetland ID	227

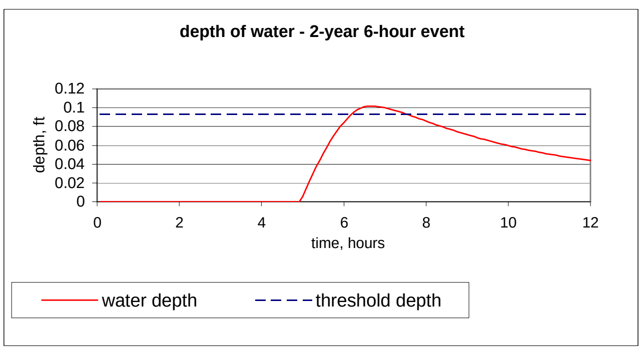
Tributary area 271 ac				
Total inflow volume, af	Maximum depth, feet	5-min peak inflow, cfs	5-min peak outfow, cfs	
12.7	0.10	83.1	6.6	2-year 6-hour event
19.1	0.28	230	34.8	100-yr 3-hour event

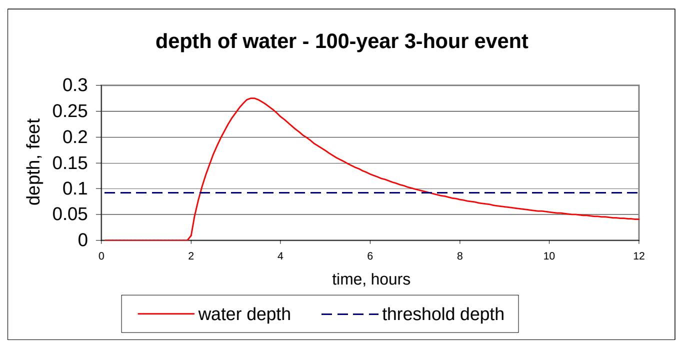






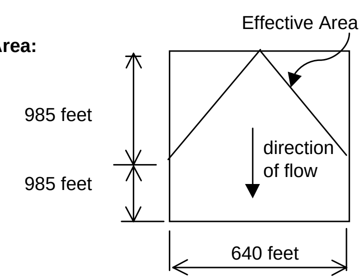






WETLAND PARAMETERS

Wetland Area:



Input

length	1970 feet
width	640 feet
slope	0.43%

Output

threshold depth:	0.09 feet
effective area	21.7 acres
intrinsic storage	EXT('2-yr 6-hr'!J18,"0.0")," acre-feet")

PERCENT OF STORM STORED BY WETLAND

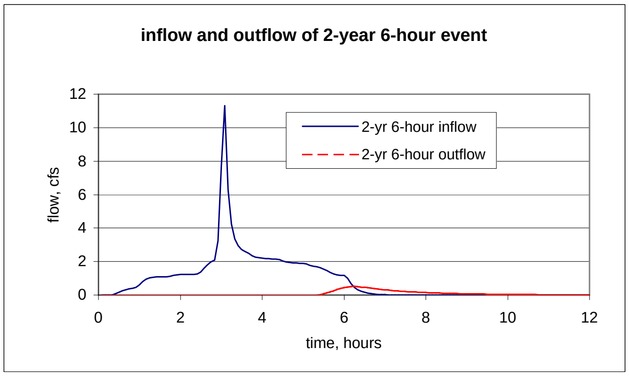
76% of 2-yr 6-hour   50% of 100-yr 3-hour

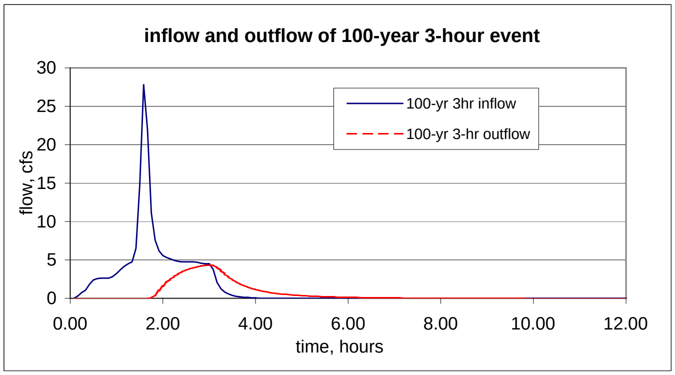
Equivalent Sedimentation Basin Size and Cost	
61 af	Pond Volume up to top of flood pool
8.0 ac	Surface Area at top of flood pool
$1,984,000	Construction Cost
$243,335	Annualized Construction and Maintenance Cost

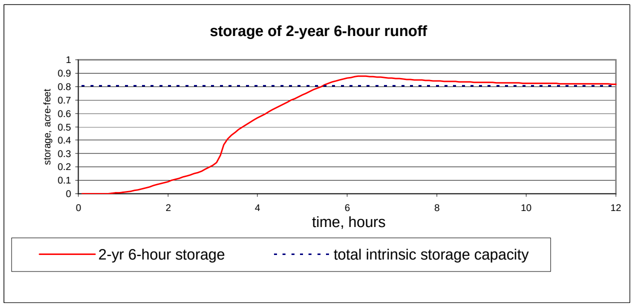
WETLANDS STORM ROUTING

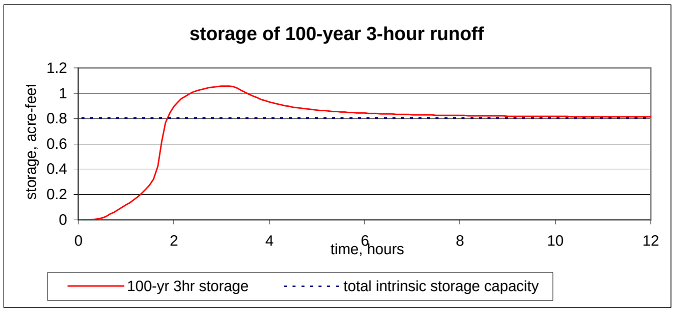
BASIN ID	69
BASIN Description	Merrill Field E - Eastridge condo outfall
FID	119
Wetland ID	227

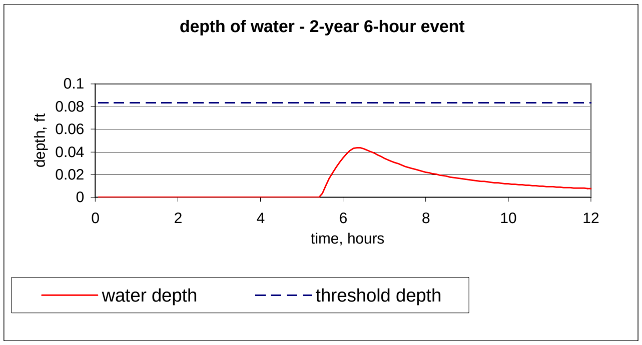
Tributary area 26 ac				ac
Total inflow volume, af	Maximum depth, feet	5-min peak inflow, cfs	5-min peak outfow, cfs	
0.9	0.04	11.3	0.5	2-year 6-hour event
1.4	0.15	28	4.3	100-yr 3-hour event

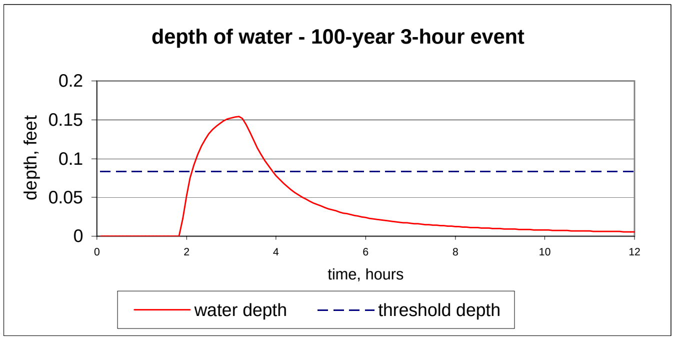












WETLAND PARAMETERS

Input

length	510 feet
width	200 feet
slope	0.50%

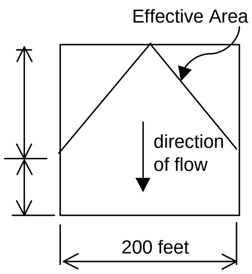
Output

threshold depth:	0.08 feet
effective area	1.6 acres
intrinsic storage	:XT('2-yr 6-hr'!J18,"0.0")," acre-feet")

PERCENT OF STORM STORED BY WETLAND

89% of 2-yr 6-hour 56% of 100-yr 3-hour

Wetland Area:

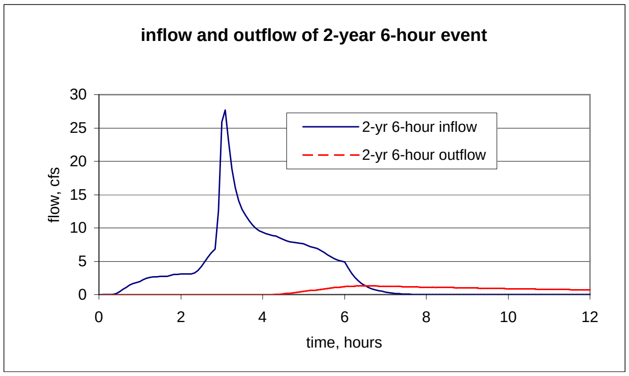


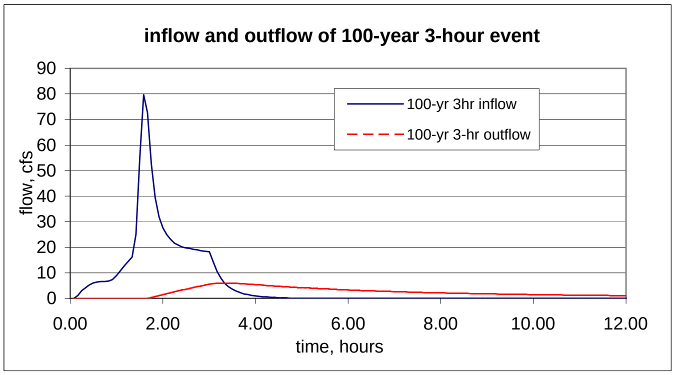
Equivalent Sedimentation Basin Size and Cost	
2 af	Pond Volume up to top of flood pool
0.5 ac	Surface Area at top of flood pool
$498,000	Construction Cost
$61,079	Annualized Construction and Maintenance Cost

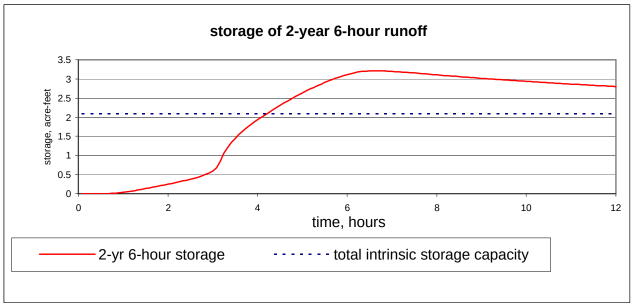
WETLANDS STORM ROUTING

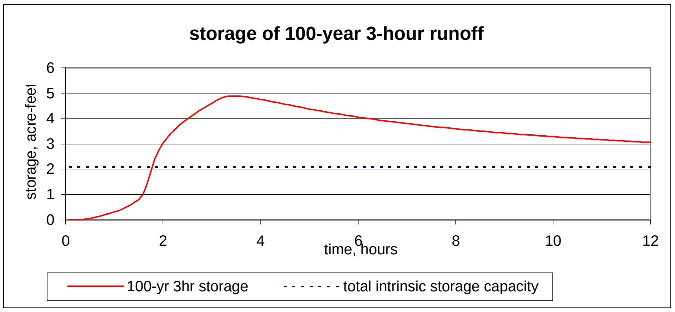
BASIN ID	88
BASIN Description	North of N Lts at UAA
FID	7
Wetland ID	251/267

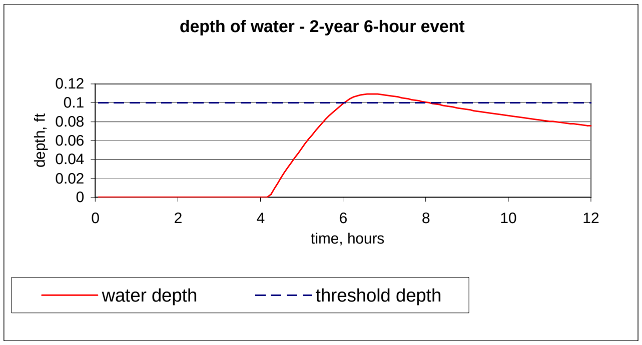
Tributary area 135 ac				ac
Total inflow volume, af	Maximum depth, feet	5-min peak inflow, cfs	5-min peak outfow, cfs	
3.4	0.11	27.7	1.3	2-year 6-hour event
5.5	0.27	80	6.1	100-yr 3-hour event

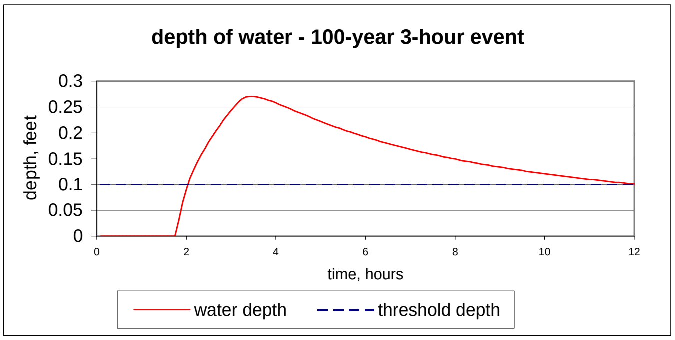






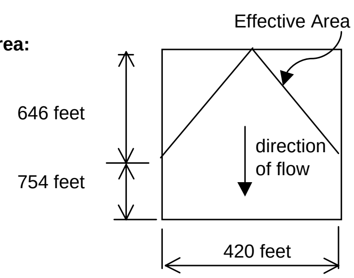






WETLAND PARAMETERS

Wetland Area:



Input

length	1400 feet
width	420 feet
slope	0.05%

Output

threshold depth:	0.10 feet
effective area	10.4 acres
intrinsic storage	EXT('2-yr 6-hr'!J18,"0.0")," acre-feet")

PERCENT OF STORM STORED BY WETLAND

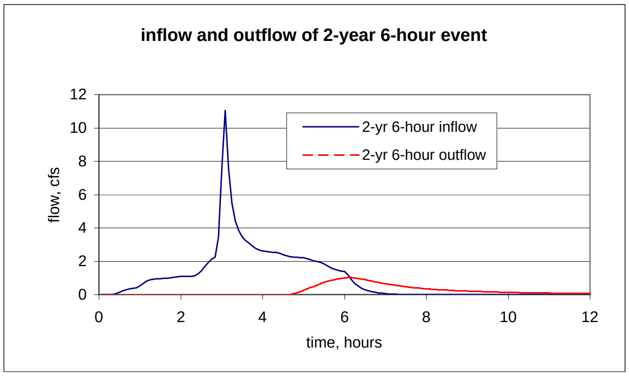
62% of 2-yr 6-hour   38% of 100-yr 3-hour

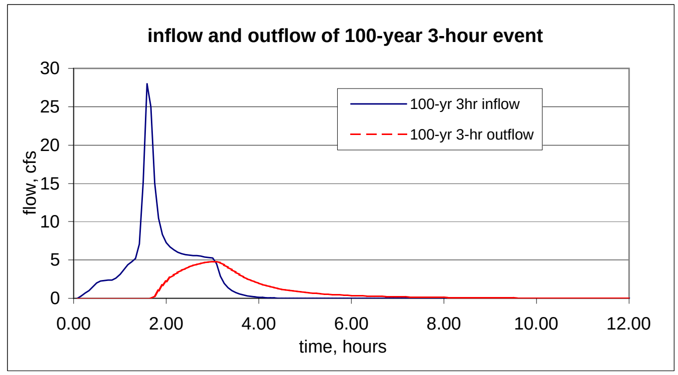
Equivalent Sedimentation Basin Size and Cost	
9 af	Pond Volume up to top of flood pool
1.6 ac	Surface Area at top of flood pool
$759,000	Construction Cost
$93,091	Annualized Construction and Maintenance Cost

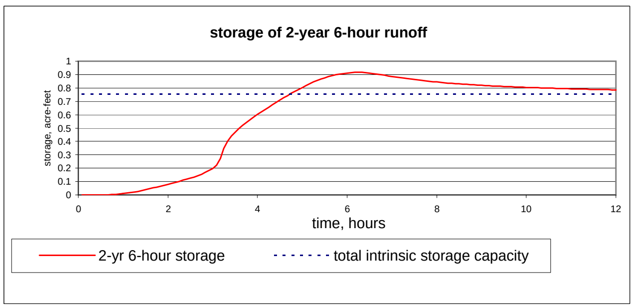
WETLANDS STORM ROUTING

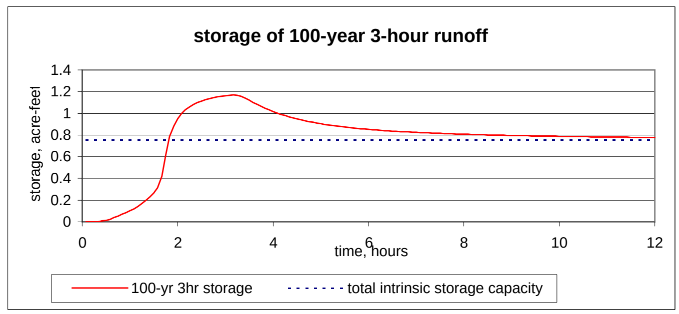
BASIN ID	106
BASIN Description	Merrill Field S of Chester Ck
FID	25
Wetland ID	227

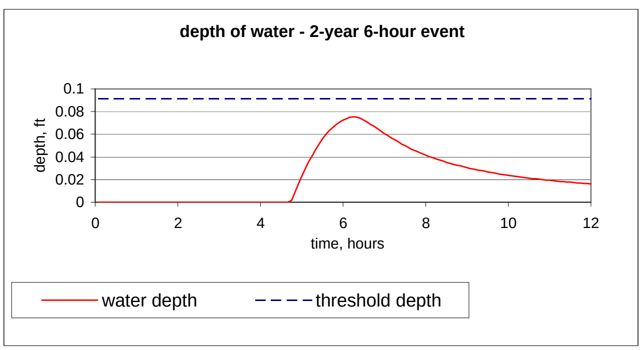
Total inflow volume, af	Maximum depth, feet	5-min peak inflow, cfs	5-min peak outflow, cfs	Tributary area 28 ac
1.0	0.08	11.1	1.0	2-year 6-hour event
1.6	0.19	28	4.8	100-yr 3-hour event

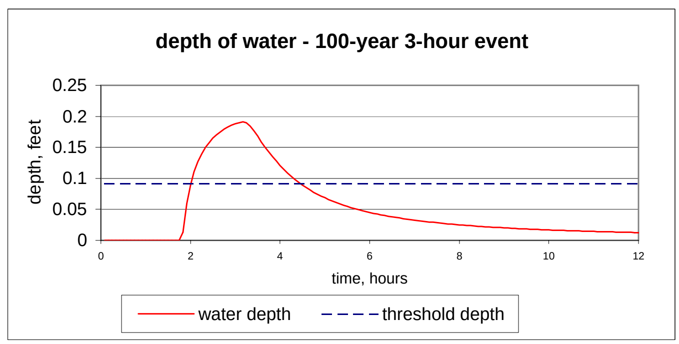












WETLAND PARAMETERS

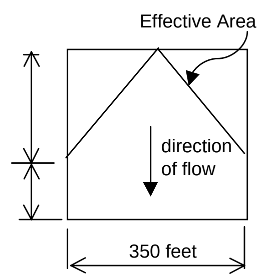
Wetland Area:

Input
length 540 feet
width 350 feet
slope 0.26%

Output
threshold depth: 0.09 feet
effective area 2.2 acres
intrinsic storage :XT('2-yr 6-hr'!J18,"0.0")," acre-feet")

539 feet

1 feet



PERCENT OF STORM STORED BY WETLAND
74% of 2-yr 6-hour   46% of 100-yr 3-hour

Equivalent Sedimentation Basin Size and Cost	
2 af	Pond Volume up to top of flood pool
0.5 ac	Surface Area at top of flood pool
$499,000	Construction Cost
$61,202	Annualized Construction and Maintenance Cost

Appendix E
Bibliography

Bibliography

Asselin, Stephane, et al. 1996. Hydraulic Studies for a Large Wetland. North American Water and Environment Congress & Destructive Water. pp 512-517.

Daniel, J.A. and J.A. Staricka. 2000. Frozen Soil Impact on Ground Water-Surface Water Interaction. Water Resources Bulletin - AWRA. 36(1). pp 151-160.

Hammer, D.E. and R.H Kadlec. 1986. A model for wetland surface water dynamics. Water Resources Research. 22(13). 1951-1958.

Hodges, Clayton, et al. 1997. Resistance to Flow through Riparian Wetlands. Proceedings for Theme B: Water for a Changing Global Community. 27th Congress of the International Association for Hydraulic Research. San Francisco, CA. Aug 10-15 1997. pp 913-918.

Lee, E.R., S Mostaghimi, T.M. Wynn. 2002. A model to enhance Wetland Design and Optimize Nonpoint Source Pollution Control. Water Resources Bulletin - AWRA. 38(1). pp 17-32.

Loftin, C.S., W.M. Kitchens, N. Ansay. 2001. Development and Application of a Spatila Hydrology Model of Okefenokee Swamp, Georgia. Water Resources Bulletin - AWRA. 37(4). pp 935-956.

Kadlec, R.H., D.E. Hammer, In-sik Nam, J.O. Wilkes. 1981. The hydrology of overland flow in wetlands. Chemical Engineering Communication. Vol 9. No. 9:331-344.

Kadlec, R.H. 1990. Overland flow in wetlands: vegetation resistance. Journal of Hydraulic Engineering. 116(5). pp 691-706.

Roig, L. C. and I.P. King. 1992. Continuum Model for Flows in Emergent Marsh Vegetation. Proceedings of the 2nd International Conference on Estuarine and Coastal Modeling, ASCE. Tampa, FL. Nov 13-15 1992. pp 268-279.

Roig, Lisa C. 1995. Mathematical Theory and Numerical Methods for the Modeling of Wetland Hydraulics. Proceedings of the First International Conference San Antonio TX Aug 14-15 1995. pp 249-253.

Tai, C. Charles and Chou Fang. 1995. Hydraulics of Shallow Water Flow in a Marsh Flowway. Proceedings of 22nd Annual Conference. Cambridge MA. May. 7-11 1995. pp 356-359.

Thackston, E.L., F.D. Shields, P.R Schroeder. 1987. Residence Time Distributions of Shallow Basins. Journal of Environmental Engineering, ASCE. 113 (6). pp 1319-1332.

Tisdale, Todd S. 1989. Low-Land Hydraulics and Hydrodynamics. Hydraulic Engineering. pp 788-794.

Walters, Michael, et al. 1995. H&H Modeling in High Water Table - Low Relief Area. proceedings of the International Water Resources Engineering Conference. Memphis TN. Aug 3-7 1998. pp 622-627.

Walton, Raymond, et al. 1989. Numerical Model Studies of Wetland Hydraulics for Bolsa Bay, CA. Hydraulic Engineering. pp 236-241.

Walton, R. et al. 1993. Modeling Wetland Hydrologic and Hydraulic Processes. Proceedings of Symposium sponsored by Hydraulics Division of ASCE San Francisco CA July 25-30 1993. pp 138-143.

Wang, Flora C., J.S. Wei, Julie Amft. 1989. Simulation of Wetland Hydrology and Hydrodynamics. Hydraulics and Hydrology in the Small Computer Age. pp 283-288.

Wilsnack, M.M. , D.E. Welter, A.M. Montoya, J.I. Restrepo, J. Obeysekera. 2001. Simulation Flow in Regional Wetlands with the MODFLOW Wetlands Package. Water Resources Bulletin - AWRA. 37(3). pp 655-674.