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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Flow area of a cross section</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Kinetic energy correction factor</td>
</tr>
<tr>
<td>C</td>
<td>Coefficient of contraction or expansion</td>
</tr>
<tr>
<td>g</td>
<td>Gravitational acceleration</td>
</tr>
<tr>
<td>$h_i$</td>
<td>Head loss between two cross sections</td>
</tr>
<tr>
<td>$h_o$</td>
<td>Contraction and expansion head loss</td>
</tr>
<tr>
<td>K</td>
<td>Conveyance of a cross section</td>
</tr>
<tr>
<td>L</td>
<td>Discharge weighted reach length between two cross sections</td>
</tr>
<tr>
<td>n</td>
<td>Manning's roughness coefficient</td>
</tr>
<tr>
<td>P</td>
<td>Wetted Perimeter</td>
</tr>
<tr>
<td>Q</td>
<td>Discharge</td>
</tr>
<tr>
<td>R</td>
<td>Hydraulic Radius</td>
</tr>
<tr>
<td>$S_f$</td>
<td>Energy slope / friction slope between two sections</td>
</tr>
<tr>
<td>V</td>
<td>Flow Velocity</td>
</tr>
<tr>
<td>$x'_{ij}$</td>
<td>Standardized score for the $i$th (alternative) and the $j$th attribute,</td>
</tr>
<tr>
<td>$x_{ij}$</td>
<td>Raw score</td>
</tr>
<tr>
<td>$x_{j}^{\text{max}}$, $x_{j}^{\text{min}}$</td>
<td>Maximum and minimum scores for the $j$th attribute</td>
</tr>
<tr>
<td>$x_{j}^{\text{max}} - x_{j}^{\text{min}}$</td>
<td>Range of a given criterion</td>
</tr>
<tr>
<td>Y</td>
<td>Depth of water</td>
</tr>
<tr>
<td>Z</td>
<td>Main channel invert elevation</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>AHP</td>
<td>Analytic Hierarchy Process</td>
</tr>
<tr>
<td>CDF</td>
<td>Confined Disposal Facility</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>DLG</td>
<td>Digital Line Graph</td>
</tr>
<tr>
<td>DMRP</td>
<td>Dredged Material Research Program</td>
</tr>
<tr>
<td>DTM</td>
<td>Digital Terrain Model</td>
</tr>
<tr>
<td>EEDP</td>
<td>Environmental Effects of Dredging Program</td>
</tr>
<tr>
<td>ESRI</td>
<td>Environmental Services Research Institute</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>HEC-RAS</td>
<td>Hydrologic Engineering Center River Analysis System</td>
</tr>
<tr>
<td>IDW</td>
<td>Inverse Distance Weighted</td>
</tr>
<tr>
<td>MADM</td>
<td>Multiattribute Decision Making</td>
</tr>
<tr>
<td>MCDM</td>
<td>Multicriteria Decision Making</td>
</tr>
<tr>
<td>MODM</td>
<td>Multiobjective Decision Making</td>
</tr>
<tr>
<td>MWCD</td>
<td>Muskingum Watershed Conservancy District</td>
</tr>
<tr>
<td>SAW</td>
<td>Simple Additive Weighting</td>
</tr>
<tr>
<td>SCS</td>
<td>Soil Classification System</td>
</tr>
<tr>
<td>TIN</td>
<td>Triangulated Irregular Network</td>
</tr>
<tr>
<td>USACE</td>
<td>United States Army Corps of Engineers</td>
</tr>
<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
</tr>
<tr>
<td>WLC</td>
<td>Weighted Linear Combination</td>
</tr>
</tbody>
</table>
Dredging is defined as the excavation or movement of soil or rock with a dredger, a vessel equipped with the means to move or excavate soil or rock underwater (Herbich, 1997). Dredging may be carried out for many reasons by a number of different types of dredgers in various environments. Within these environments, approximately 400 million cubic yards of sediment are removed from waterways and ports each year in the U.S. to improve and maintain the nation’s navigation system. Alternatives for the disposal and use of dredged material must be carefully evaluated. Until the 1970s, the practice of dredging focused on the efficiency of the dredging operation and production capacity. Major environmental legislation has inspired the dredging process to include a broad range of environmental considerations.

Dredged material may encourage the restoration and creation of wetlands. At several US Army Corps of Engineers sites around the country, dredged material has been used to create new wetlands and to restore degraded wetlands. Due to a lack of definitive guidelines for site selection, preparation and operation and maintenance, levels of restoration or creation “success” have been unknown for these projects in part. This chapter introduces different dredging methods, in particular the cutter suction dredge, the potential uses of dredged material, and the uses of geographic information systems for selecting sites for dredged materials.
The most common objective of dredging is to remove materials from a
undesirable location and to place them at in an acceptable location. Also, the goal may
be to remove materials from a particular location to a new location by natural forces.
This is the simplest dredging process known as ‘agitation dredging’. Agitation dredging
involves disturbing bed materials by forcing them into suspension, after which they may
be moved by natural water flow and then redeposited elsewhere (Bray, et al., 1997).
Suspension of materials is usually achieved by raking, pumping, or with water jets. A
variation of the agitation method called water injection, involves the pressure injection of
water into settled material. This, in turn, reduces the in situ density of the bed material to
a consistency that allows the material to flow.

It is most common for dredged materials to be placed within pre-determined
areas. In such cases, the bed material is dislodged, raised and physically transported to
the deposit location. The process of dislodgement is dependent on the density, or
strength of the bed materials, and has an important influence on the choice of the
dredging method. Strong bed materials, such as rock, may require some method pre-
treatment to break up the material before dredging. Loose materials, or those of low
strength, usually do not require pre-treatment or mechanical dislodgement treatments. As
a result, suction methods are most commonly implemented. When the density of the bed
material is too high for efficient production to be achieved simply by pumping,
mechanical dislodgement is necessary. Mechanical dislodgement may be combined with
suction methods; in such cases, the material is dislodged by a cutterhead and then raised within the pumped mixture.

The cutter suction dredger is likely the most well known, efficient, and versatile dredging vessel (Herbich, 1992). This dredger, often used in works of hydraulic filling, is also implemented in a wide range of applications. The dredging process involves an initial powerful cutting action, followed by suction, and pumped discharge via a pipeline. The cutter suction dredger has the ability to handle a wide range of material, and also to convey the dredged material; this is done by pumping water directly into the disposal or reclamation area. The dredger can also operate in shallow water, produce a uniform level bottom, and dredge to a pre-determined profile such as in channels. However, the cutter suction dredger is limited not only by the depth at which dredging can take place, but also by the distance through which dredged material can be economically conveyed.

Operating the cutter suction dredger involves cutting, dislodging, or breaking up soil or rock by means of a powerful electronically or hydraulically driven crown cutter. The cutter head is mounted at the end of a fabricated steel structure called a ‘ladder’, which also supports the suction pipe. The ladder is attached to the main hull by heavy hinges that permit vertical rotation. The ladder assembly is lowered and raised by means of a hoisting winch controlled from the bridge. The suction pipe includes a length of heavy reinforced hose that is located immediately outside the pump room bulkhead.

Location control of the dredger is usually by means of a combination of ‘spuds’ and winches. The most common combination of spuds and winches employs two swing winches and two spuds. One spud is located with fixed gates at the stern of the vessel. The other ‘working’ spud may be fixed at the stern, or movable by tilting, or mounted in
a carriage that moves longitudinally or rotationally about the centerline of the dredger.

Figure I.1.1 displays the main features of the cutter suction dredge.

Figure I.1.1 Main features of the cutter suction dredger (Bray, Bates and Land, 1997)

The discharge from the dredge pump(s) passes over the stern or opposite end of the cutter to a hose or flexible coupling, which is connected to a floating pipeline. When dredging, the working spud is penetrated into the bed serving as a pivot point. The underside of the cutter is maintained at an elevation just below the desired finish grade and traversed across the width of the proposed channel. This is accomplished by rotating the dredger about the working spud, by hauling in on one swing winch and paying out the other. The dredger is advanced forward a distance approximately equal to the height of
the cutterhead by stepping with fixed spuds, tilting the working spud, or advancing the working spud carriage. All spud systems work on the same basic principle that one spud is moved while the other is firmly imbedded in the ground (Bray, 1997).

I.2 Beneficial Uses of Dredged Material

In recent years numerous dredging programs such as the Dredged Material Research Program (DMRP) and the Environmental Effects of Dredging Program (EEDP) have been instrumental in increasing the number of alternatives for beneficial uses of dredged materials (Herbich, 2000). National regulation and international agreements governing the disposal of dredged materials have become more stringent. As a result, engineers were encouraged to find beneficial uses for dredged materials that previously would have been considered worthless.

Reclamation is the best known use of dredged material, and is defined as “the act of raising the level of land which is either just below or adjacent to water” (Bray, 1997). Reclamation is also the most common use of dredged material because it is less expensive to place dredged material in a reclamation area than to dispose of it at an acceptable onshore or offshore location. In the US, dredged material has been extensively used to create or restore large areas of wildlife habitat. The use of dredged material for habitat development offers a disposal technique that is an attractive and feasible alternative to more conventional disposal options. Many island habitats have been developed with dredged materials such as, seagrass meadows, oyster beds and fishing reefs.
Dredged materials have also been used to provide shoreline stabilization, erosion control and beach nourishment. Material extracted from dredging operations may be used for capping, by placing the dredged material over contaminated material, in order to prevent the resuspension of the contaminated sediment. Given the composition and mineral and organic content in some cases, dredged material has been used as topsoil. Dredged material disposal sites have also been used by the agriculture, forestry, and horticulture industries. Industrial and commercial development near waterways can be aided by the availability of hydraulic fill material from nearby dredging activities.

Dredged material is commonly used in the construction of dikes and levees; this, in turn, can reduce project costs by avoiding the use of off-site material. Implementing careful engineering design, construction, long-term coordination and planning, along with proper implementation of operational and maintenance procedures, a disposal site with combinations of uses may be developed (Herbich, 2000).

1.3 Use of Geographical Information Systems

Geographical information systems (GIS) are defined as computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information (Tate, 1999). Originally developed as a tool for cartographers, GIS has recently gained widespread use in engineering design and analysis, especially in the fields of water quality, hydrology, and hydraulics. GIS provides a means to overlay layers of data and perform spatial queries; new spatial data is created. Results can be digitally mapped and tabulated, allowing for efficient analysis and decision-making.
Structurally, GIS consists of a computer environment that joins graphical elements (points, lines, polygons, grids) with associated tabular attribute descriptions. This characteristic sets GIS apart from both computer-aided design software (geographic representation) and databases (tabular descriptive data). It has the ability to perform numerous tasks utilizing both the spatial and attribute data stored within it (Malczewski, 1999). Vector feature representation is typically used for linear feature modeling (roads, lakes, etc.), cartographic base maps, and time-varying process modeling. The raster data structure consists of a rectangular mesh of points joined with lines, creating a grid of uniformly sized square cells. Each cell is assigned a numerical value that defines the condition of any desired spatially varied quantity. Grids are the basis of analysis in raster GIS, and are typically used for steady-state spatial modeling and two-dimensional surface representation.

The ArcView GIS software package, developed by the Environmental Systems Research Institute (ESRI), was used as the computer development environment for this research. In the past several years, ArcView has emerged as the industry leader in desktop GIS software.

1.4 Nature of the Study

Many different methods exist to aid in the selection of preliminary sites for the disposal of dredged materials. This study investigates the use of geographic information systems (GIS) to develop a model for evaluating potential disposal sites within the Charles Mill Lake. The study also analyzes the effect of placing inshore disposal sites at
the mouth of the incoming stream for Charles Mill. In the past, interpolated surfaces and topologies have been constructed using GIS in combination with water surface profile computation for floodplain studies (Shi, 2000). This study uses those techniques to explore the changes in floodplain delineation by altering channel geometries due to the placement of dredged material.

Determining potential disposal sites requires evaluating a set of criteria. The criteria were derived from data that was acquired from numerous agencies. This was then processed using different methods of interpolation and multicriteria decision analysis. Digital topography and hydrography data were downloaded from the USGS’ GIS support center website. All known water surface elevations were obtained from the United States Army Corps of Engineers (USACE). All data points used for the development of the bathymetric surface of the Charles Mill Lake were also acquired from the USACE. Analysis of the distribution and classification of sediment within Charles Mill was obtained from the results of a survey performed by Bayes (1998). Finally, the Muskingum Watershed Conservancy District (MWCD) provided information pertaining to the adjacent land use and current dredging methods.

Water surface profile computation was done with the application of the AVRas extension. AVRas enables users to use ArcView GIS desktop to develop HEC-RAS models integrated with digital terrain models and other GIS data sets to produce inundation maps. The inundated areas are created from river geometry and model parameters by an existing digital terrain model (DTM). By altering the river geometry and reproducing the water surface profiles, changes in the amount of inundated area can be analyzed.
1.5 Objectives of the Study

Many aspects need to be considered during the selection process of preliminary sites for disposing dredged material. Evaluation of such aspects has not typically been performed using GIS. Utilizing GIS to process and evaluate decision criteria will greatly improve accuracy and the scale to which such analyses can be performed. The objective of this study will be to evaluate areas along the shores of the Charles Mill Lake that would be most suitable for the development of wetlands using GIS. Given the speed and efficiency of today's computers, the model developed in this study will also attempt to analyze the project area in a high resolution.

The Black Fork Creek is the main stem providing the Charles Mill Lake with water. The placement of a disposal site at the mouth of the river will reduce its cross sectional area and constrict flow entering the reservoir. One of the objectives is to compute the water surface profiles and display the changes of inundated area upstream of the Black Fork Creek due to disposal siting. To accomplish this, the geometry of the creek will be constructed and hydraulic flow computations will be performed based on the placement of a disposal site.

The study area consists of the Charles Mill Lake and its surrounding areas located within the north central part of Ohio. The lake is located four miles east of Mansfield, Ohio, in both Richland and Ashland counties. The lake receives its inflow from the Black Fork Creek, located at the north end of the lake. The lake was built in 1935 for the purpose of flood control originally and of conservation later. The dam is owned and operated by the USACE. The water from the Charles Mill Lake is discharged into the
Muskingum River, which ultimately discharges into the Ohio River. The conservation and recreation of the lake and surrounding lands are managed by the Muskingum Watershed Conservancy District (MWCD), which is the largest conservancy district in Ohio.

The lake has lost approximately 20% of its volume since its construction in 1935 (Bayes, 2000). The MWCD has implemented a dredging operation since 1998. The dredging of the lake began where the sedimentation was the worst, just north of the US Route 30 bridge. The operation is being conducted to create navigable channels where access has become a problem. Dredged materials have been used to create wetlands to enhance waterfowl breeding and fish habitat (MWCD, 1999). Table I.5.1 lists additional physical features of the Charles Mill Lake. Figure I.5.1 shows the location of Charles Mill Lake and its surrounding area.

Development of procedures to optimize the locations of dredged material for beneficial uses will not only benefit the flora and fauna involved, but also all of the surrounding forms of life. This study will hopefully not only encourage others to remain as environmentally conscientious as possible when considering the implementation of a project that may impact the environment, but also to provide a tool to achieve it.
### Table I.5.1 Physical Features of Charles Mill Lake and Its Watershed

<table>
<thead>
<tr>
<th></th>
<th>Lake Length</th>
<th>20,700 feet</th>
<th>6,300 meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Breadth</td>
<td></td>
<td>6,200 feet</td>
<td>1,900 meters</td>
</tr>
<tr>
<td>Maximum Depth</td>
<td></td>
<td>27 feet</td>
<td>8.2 meters</td>
</tr>
<tr>
<td>Water Surface Area (normal pool)</td>
<td></td>
<td>1339.5 acres</td>
<td>5.42 km²</td>
</tr>
<tr>
<td>Shoreline Length</td>
<td></td>
<td>34 miles</td>
<td>53.5 km</td>
</tr>
<tr>
<td>Lake Elevation (normal pool)</td>
<td></td>
<td>997.1 feet (MSL)</td>
<td>304.0 meters</td>
</tr>
<tr>
<td>Lake Elevation (spillway)</td>
<td></td>
<td>1020.0 feet (MSL)</td>
<td>311.0 meters</td>
</tr>
<tr>
<td>Watershed Area</td>
<td></td>
<td>217 mile²</td>
<td>562 km²</td>
</tr>
</tbody>
</table>
Figure I.5.1 Map of Charles Mill Lake and Surrounding Area
CHAPTER II
SELECTED LITERATURE REVIEW

II.1 Disposal and Placement of Dredged Material

The disposal of dredged materials can be classified into three major categories; open-water, confined (diked) disposal, and beneficial use (Palermo, 2000). Open-water disposal involves the placement of dredged material in rivers, lakes, estuaries, or oceans, usually through a pipeline. Confined disposal involves the placement of dredged material within a diked island, nearshore or upland in confined disposal facilities via pipeline or some other means. The disposal of dredged material for beneficial use involves the placement or use of the material for some productive purpose.

Since the 1970s, environmental considerations have played a major role in selecting disposal alternatives. Potential impacts on the environment resulting from the disposal of dredged materials may be physical, chemical, or biological. Examples of these effects will be discussed further in subsequent sections. Sound planning, design, and management of a dredging project is essential if an appropriate and environmentally compatible disposal alternative is to be chosen effectively. The selection of an appropriate alternative is based on a number of considerations including environmental acceptability, technical feasibility, and economics among others (Palermo, 2000).
II.1.1 Disposal Alternatives

Dredged material can be placed in open-water sites using direct pipeline discharge, direct mechanical placement, or release from a hopper dredge. Material generated from the operation consists of slurry with solids concentration stretching over a relatively wide range. The slurry may contain clay balls, gravel, or coarse sand. As the material is discarded, coarse material quickly settles, while fine material that remains suspended in a turbid plume is lost during the descent.

When considering the disposal action of the hopper dredger, the ship first transports the material to the disposal site. The hopper doors in the bottom of the ship are opened and the dredged material is released. Upon release, the material falls through the water column as a well-defined jet of high-density fluid which may contain blocks of solid material (Herbich, 2000).

Open-water disposal sites can be either predominately nondispersive or predominately dispersive. Dispersive sites intend for the majority of the material to remain on the bottom following placement. At nondispersive sites, material may be dispersed during placement or eroded from the bottom and transported away by currents and/or wave action. Either type of site can be managed in numerous ways to sustain environmental compatibility. Site characteristics must be investigated in order to assess any potential physical and contaminant impacts while considering open-water disposal. Information regarding currents, wave climate, water depth and bathymetry is needed to assess a potential open-water disposal site.
Confined Disposal Facilities (CDF) may take on several forms: upland sites, nearshore sites (partially in or out of the water), or islands. The design of a CDF is greatly dependent on the method of dredged material placement. Hydraulic means of dredging add a large volume of water for sediment removed. The excess water is usually discharged during the fill process of the CDF. When dredged material is initially deposited in a CDF, its volume may be several times greater than its design intended. Consolidation of the sediment is a function of time; therefore, adequate volume must be provided during the dredging operation in order to compensate for any volume changes during filling. CDFs are typically used over a period of many years, but can be used for one-time or multiple placements. As a result, long-term storage capacity of these CDFs is a major factor in design and management.

Outer boundaries of a confined disposal facility usually consist of dikes. For upland sites, they are commonly constructed from available soil at the site. Nearshore or island dikes may be constructed by dredging suitable bottom sediment or using imported materials (Bray, 1997). Generally, no inlet structures are incorporated into the design of CDF dikes, but there are usually a series of inflow points. These inflow areas allow for a more uniform distribution within the disposal area. The rate of effluent of the CDF is regulated by a weir structure. Weirs may be constructed from sheet steel in the form of a box, or may involve more elaborate designs. Site selection for CDFs can be a complex process, especially for open-water sites. Aside from real estate considerations in dealing with easements and rights of way, consideration must be given to the fact that the site is
regularly visible to the public and may be viewed as a conflict of interest in terms of land use and land preservation.

Containment areas are usually sized on an evaluation of volume changes that occur during dredging and placement (Palermo, 2000). Also considered are required surface areas and ponding depths to maintain an acceptable effluent quality. Preliminary sizing should consider anticipated ponding depths, dike heights, duration of dredging and available surface area. Sizing requirements are dependent on the results of column-settling tests. Tests are used to define dredged material’s settling properties and the required ponding area and depth to maintain acceptable water quality standards. The disposal area can be any shape, but is generally dictated by the shape of the land available. Figure II.1.1 shows an example of an irregularly shaped containment area.

Figure II.1.1 Irregular shape of containment area as dictated by surrounding terrain
Dredged material slurry pumped into a containment area may contain a large range of particle sizes and sediment characteristics. The settling and dewatering of the slurry depends on the type of material (Palermo, 2000). While coarse-grained materials drain freely, fine-grained materials are difficult to dewater. During the disposal process, a natural segregation occurs when the dredged material is pumped into a containment area. A mound of coarser material may form near the discharge pipe while finer materials are carried away in suspension and deposited by settling away from the point of discharge.

If economically feasible, selective dredging can be performed. If the composition of the sediment is well known prior to dredging, different types of materials can be dredged and pumped into different containment areas by layers. Advantages of selective dredging are that the dewatering of coarse-grained material will occur more quickly, therefore speeding up the filling of the disposal area. Also if a specific material is required on a given project, selective dredging may be considered in order to isolate any desired material types.

If a CDF is intended for one-time use, initial storage capacity and solids retention during filling are the only design considerations. For a long-term use, the long-term storage capacity of the CDF must be considered. Assuming that a CDF occupies a given surface area, the storage capacity that remains at any time will be a function of the dredged material fill height (Herbich, 1992). As additional material is added, sedimentation of the suspended solids occurs and the fill height increases. After the CDF
is filled, the fill height will decrease due to continued sedimentation, consolidation and desiccation.

While sedimentation of course-grained dredged material occurs relatively quickly and will occupy essentially the same volume as they did prior to dredging, fine-grained materials require longer settling times and initially occupy considerably more volume than they did prior to dredging. These materials will undergo a considerable degree of long-term volume change from consolidation, which takes place because of self-weight loading. A loading is also imposed on the containment area foundation, and may result in additional settlement. Settlement from consolidation is a major factor in the estimation of long-term storage capacity (Palermo, 2000).

The final method of disposal for dredged material is for beneficial purposes. As previously presented, some of the beneficial uses of dredged material are elaborated with particular focus on the development of wetland habitats. Wetlands are considered to be any community of grasses or herbs that experience periodic or permanent inundation (Herbich, 2000). Wetlands are recognized as extremely valuable natural systems and are vital in food production, fish and wildlife cover, nutrient cycling, erosion control, floodwater retention, groundwater recharge and aesthetics. A wetland with marsh development is one placement alternative that can expect to generate strong public appeal. The restored or created habitat has biological values that are readily identified and accepted in the academic, governmental and private sectors.

A created wetland, however, differs from a restored wetland. A created wetland is one in which hydrology, geomorphology, vegetation and energy protection must be
provided at a site where no wetland has ever existed (Landin, 2000). On the other hand a restored wetland is one in which one or more of the aforementioned factors are still present, as a wetland once existed at that location. Wetland restoration is much less expensive and has a much higher degree of success than wetland creation.

The most difficult aspect of initial wetland development is the location of suitable sites. Low-energy sites offer the most potential; however, transport distances to low-energy areas become significant, and results in high costs. Temporary protective structures may be necessary if low-energy sites cannot be located. Replacing one habitat with the development of another occurs frequently. Wetlands using dredged materials should be designed to be relatively maintenance free (Landin, 1995). The degree of maintenance largely depends on the energy conditions at the site.

The engineering design of wetland habitats can be divided into four areas: location, elevation, orientation, shape and size. The design should maintain goals of dredged material placement by developing a desirable biological community, using most cost-effective methods, and causing a minimum of environmental impacts (Landin, 2000). As mentioned earlier, low-energy areas best suited for wetland development. Because of this, sandy dredged material has been found to be the ideal substrate (Herbich, 2000). Particular efforts should be made to avoid areas such as seagrass meadows, clam flats and oyster beds. The final elevation of the wetland substrate is largely determined by settlement and consolidation of the dredged material. These two aspects are of critical importance since they dictate both the amount of material to be placed and the biological productivity of the habitat.
The orientation and shape of a new wetland will significantly affect its total cost, efficiency and effectiveness as a biological habitat. The shape should minimize any impacts on drainage or any current patterns in the surrounding area of the disposal site. The wetland should also be shaped to accommodate high-energy forces. The size of the disposal site is a critical function of the amount of materials dredged and the volume of the placement area. There are several filling options that effect wetland size such as one-time and incremental filling. As the name suggests, one-time filling implies that a site will be filled and developed only once. Incremental filling indicates that the same site is used for more than one dredging operation or season. Incremental filling not only offers the advantage of establishing a large placement site, but also makes the site available for utilization over a period of years. As a result, incremental filling allows costs related to repetitive construction, and design operations to be avoided.

The engineering design of substrate for wetland habitat development consists of defining elevation, slope, shape and orientation and size. The design must provide for placement of the dredged material within desired limits and required elevations, allowing for settlement due to consolidation of the dredged material and foundation soils (Landin, 2000). Adequate surface area or detention time must be provided for fine-grained sediments. Appropriate detection time ensures the settling of suspended solids in order to meet effluent standards. Design for sedimentation is directly affected by the size of the disposal site, the inflow rate, and physical properties of the sediment.
II.1.2 Planning and Design Considerations

Although many planning and design considerations for all types of disposal alternatives are the same, the focus of this study pertains to the development of wetlands using dredged material. Consequently, only the planning and design considerations for wetland habitat development will be discussed, as well as current methods of preliminary sizing and determination of site selection criteria.

Planning for the development of wetland habitats begins with the definition of the project objective and purpose. The planning phase should identify the project type as wetland creation, restoration, or enhancement. The analysis of dredging operations follows with investigation into the volume and composition of the material to be dredged. A material balance is worked out between the dredging site and the proposal wetland site in order to identify the potential for the initial expansion and subsequent consolidation of materials. Evaluation of the transport distances is then conducted to assess the economics of the project; the lower the distance, the more cost-effective the project will be (Mohan, 2000).

Information on existing topography, near-surface soils, hydrology and vegetation are all important in identifying site conditions. All existing data on past land use, aerial photographs and topographic maps should be reviewed. Possible sources of information include: U.S. Geological Survey quadrangles, Soil Classification System (SCS) soil survey maps, state geological survey maps and state department of transportation maps. Additionally, topographic, hydrographic, vegetative and hydraulic investigations are also
common means of data collection. Such investigations include identifying and assessing rights-of-way, utilities, vegetative species, plant elevations, drainage systems, channel slopes and site hydraulics (Mohan, 2000). Geotechnical, chemical and biological investigative studies are also conducted. Geotechnical investigations involve the sampling and preliminary evaluations of soils at the dredging location and wetland site. Properties such as water content, grain size, specific gravity, consolidation, and strength tests are obtained and performed. This information is best utilized if it can be incorporated into a GIS for the site (Mohan, 2000).

Preliminary sizing of a proposed wetland is determined following data collection and analysis. The primary controlling factor in the preliminary sizing of a wetland is the amount of land available. This is because since the aerial extent is strictly limited by the amount of land available for development. The final elevation of the site is mainly controlled by the requirements of the habitat and plant species to be incorporated into the wetland.

The desired capacity for the storage of dredged materials over the life of a site is defined as the site capacity (Herbich, 2000). Depending on a project’s needs and dredged material availability, sites may be designed as single-use or multiple-use sites, similar to one-time and incremental filling operations described earlier. Site life is also assessed, but applies to multiples-use sites by evaluating the maximum potential life of the site. Time-varying factors such as bulking and consolidation/shrinking of the dredged material are also considered.
Wetland design is a function of several aspects including hydrology (water budget, tidal range, wave forces), geomorphology (soil types, sedimentation rate), and vegetative types (Kusler and Kentula, 1989; Landin, 1988; Lyle, 1985; Mohan, 1999). The design process usually involves ten steps as given in Figure II.2.2.

![Wetland Design Flow Chart](image-url)

**Figure II.1.2** Wetland Design Flow Chart
Different site selection criteria are considered for the design of a wetland habitat. Geographical criteria are considered, such as the distance from the dredging site(s) to the wetland location and the geometry of the wetland. From a cost point of view minimizing the distance from the dredging site(s) is preferred. The water depth at the site, tidal range, velocity and direction of currents are physical considerations that effect site construction and maintenance costs. Regional hydrodynamics should also be evaluated to assess potential impacts on sedimentation patterns (Herbich, 2000). Specific erosion control measures may become necessary if the expected hydrodynamic forces become excessive. Potential impacts on water quality and the presence of contaminants at the site should also be considered.

Hydrologic design and water budget typically involve a description of the spatial and temporal variability of surface water, groundwater and tides. Aspects involved in the hydrologic design for a potential wetland include flow velocity, hydraulic retention time, surface area and hydroperiod. Water budget is another important design aspect; this represents the total water exchange in the wetland.

II.1.3 Environmental Effects

Potential adverse effects of dredging and related operations can be categorized according to the nature of the activity, whether it be the dredging itself, transport of materials or relocation of materials on or off-shore. These categories can further be divided into effects that are short-term, long-term or even permanent. In order to study
environmental impacts of dredging activities, it is necessary to examine aspects such as areas, types, measurements and controls of impacts (Bray, 1997).

Potential impacts of dredging involve interference with marine and river traffic, noise generated by the dredging, turbidity, and suspended sediment. Stationary dredgers and floating pipelines can often obstruct other marine traffic. This is a short-term effect, but is one that can be minimized by establishing some system of traffic regulation. Most dredging activities are relatively quiet; however, the pre-treatment of rock can often be very noisy. The rock drills and compressors used during the pre-treatment process have been known to cause as much disturbance as some blasting operations.

Effects on the aquatic environment from dredged material resuspension are especially evident in seawater climates. Increase in turbidity is one of the most important physical impacts of dredging activities. The cloudiness associated with turbidity can cause considerable unfavorable public response to some dredging projects. The increase in turbidity is known to attenuate light and to distribute bacteria and fungi (Herbich, 1992). Turbidity not only decreases the availability of food and the effects the migration of mobile organisms, but is also aesthetically displeasing.

The potential for sediment resuspension varies according to dredger types and modes of operation (Bray, 1997). The cutter suction dredge, as mentioned, is the type of dredger used by the MWCD. Several causes of sediment resuspension exist from the operations of the cutter suction dredger. Ground disturbance around the cutterhead, biogenic gas released from sediments, impact and removal of spuds, and leaking discharge pipelines are potential causes of sediment resuspension. Usually, the
disturbance of the ground around the cutterhead is what contributes most to sediment resuspension. According to Bray (1997), high suspended sediment concentrations are confined to a small area close to the bottom and within a few meters of the cutterhead. Because they are able to work in fairly confined areas and in shallow water, most cutter suction dredgers have the advantage of operating accurately, both vertically and horizontally. Research has also shown that sediment loss increases with more cutter rotation and swing speeds.

In recent decades, environmental protection has become vital to the success of a projects implementation. Through environmental investigations and impact assessments, minimizing environmental impacts is more attainable. Environmental investigations should be directed toward aspects of a dredging project including dredging and relocation of dredged materials, the transport and replacement of reclamation fill, and all other construction activities.

**II.2 Surface Interpolators**

An interpolator is an algorithm of mathematical equations that produces a physical or abstract surface which can then be modeled. The surface can be either a contiguous set of zones, or mathematical functions. Each zone has a single value associated with it, and every point has a value that can be evaluated with mathematical functions.
Interpolation is most commonly used within a GIS where surfaces are typically generated from a set of data or sample points. From an environmental standpoint, topographic surfaces, bedrock surfaces and groundwater tables are examples of surfaces that are generated from available data. Because of high costs and limited resources, data collection of sample points can only be conducted in selected point locations with limited numbers. The points’ attributes may include several different types of information including, elevation, temperature, or any other physical properties. In order to generate a continuous surface representing the area that data were collected from, an interpolation method must be used to estimate surface values at the locations where no samples or measurements were taken. Thus, the accuracy of subsequent surfaces analyses directly depends on the accuracy of the surfaces generated.

Many interpolators exist and use different methods to generate a surface. Depending on the attribute being interpolated and the results desired, investigation on the data should be conducted in order to choose the most suitable interpolator. No method works universally as the best for any data set. A good understanding of the data set is essential in creating a surface that best represents real world conditions. The time taken to explore, understand, and describe the data set should be thoroughly performed in order to choose the most suitable interpolation method (Issaks and Srivastava, 1989).

The method in which spatial interpolators use input data is one way of classifying them. Local interpolators involve selecting data points to be used in the interpolation. Global interpolators utilize all of the available data points to form a surface. Local interpolators use a specified number of neighboring data points. Interpolators can be
either deterministic or stochastic; however, most use deterministic approaches in developing a surface. Those that rely on statistics include error variations that can be seen when mapped.

The output data structure can also be used to categorize interpolators. Some interpolators are raster-based meaning they result generally in grid values to interpolate a surface. The surface that is produced is in the form of a grid, with each cell of the grid containing a unique value. Other interpolators are vector-based, and can use both point and line data to generate a surface. A set of polygons or a Triangulated Irregular Network (TIN) results when applying a vector-based interpolator. Vector-based interpolators are more suitable for surfaces with abrupt changes in elevation, while raster-based interpolators are more suitable for gradually changing surfaces.

Interpolators can also be classified by the transition and exactness of the output data structure; the transition applies to changes in the surface. Some interpolations result in a surface of faces that are either joined at angles or at different heights. As a result, abrupt changes in the surface may occur. The exactness of an interpolator refers to whether the output result for an area of an original data point is equal to the value of that data point (Bayes, 2000).

Three methods for creating surfaces within ArcView GIS were used for this study: the Spline, Inverse Distance Weighted (IDW) and triangulation methods. Each method has advantages and disadvantages, but no individual method works universally as the best for all data sets. Selection of a particular method depends on the distribution of data points and the study objective.
The Spline interpolator is a general-purpose interpolation method that fits a minimum-curvature surface through the input points. This method of interpolation is popularly known for its ease of use and the excellent results it produces. Conceptually, it is like bending a sheet of rubber to pass through certain points, while minimizing the total curvature of the surface (ESRI, 1997). A mathematical function is fitted to a specified number of the nearest input points while passing through the sample points; however, due to the elasticity of this model, large gradients can occur. To account for these variations, stiffness can be applied to the model by using a phi factor. When the phi factor approaches infinity, the surface represents a rubber sheet.

The variations of the Spline interpolator that are incorporated in ArcView GIS are the regularized and tensions methods. The Regularized method yields a smooth surface in which a weight parameter defines the weight of the third derivatives of the surface in the curvature minimization expression (ESRI, 1997). The Tension method tunes the stiffness of the surface according to the character of the modeled phenomenon. Selection of the Tension method defines the weight of tension with the phi factor.

The Spline interpolator is best for gently varying surfaces such as land surface elevations, water table elevations, or pollution concentrations. It is not appropriate if there are large changes in the surface within a short horizontal distance. The main benefit of using splines as opposed to stochastic interpolators is that splines do not require estimation of spatial auto-covariance structure (Bayes, 2000). This method imposes that the surface must pass through the data points, and the surface must have a minimum curvature.
The Inverse Distance Weighted (IDW) interpolator assumes that each input point has a local influence that diminishes with distance (ESRI, 1997). It weights the points closer to the processing cell greater than those farther away. A specified number of points, or all points within a specified radius, can be used to determine the output value for each location. A power parameter is available in ArcView GIS that adjusts the IDW interpolator to better fit a given set of data. The power parameter controls the significance of the surrounding points upon the interpolated value. A higher power results in less influence from distant points. Barrier line themes can also be created as a break that limits the search for input sample points. A line can represent a cliff, ridge, or some other interruption in a landscape.

Some of the advantages of the IDW method are its simple underlying principle, speed of calculation, and reasonable results for varied types of data. Disadvantages are increased ambiguity with the selection of different power values. Also, when the characteristics of underlying surface are not known, the interpolation can be easily affected by uneven distribution of data points, since an equal weight will be assigned to each of the data points even if it is in a cluster. Maximums and minimums in the interpolated surface can only occur at data points, since the inverse distance weighted interpolation is, by definition, a smoothing technique (Hu, 1995).

The triangulation method generates surfaces represented by an irregularly spaced network of points or TIN. Triangulation can generate interpolated surfaces from many different data sources, such as point data, lines, breaklines, and polygons. The speed of interpolation using triangulation has become a popular interpolation method because of
this flexibility. There are several triangulation methods available (Watson, 1992). As an example, Delaunay triangulation is used because triangles are as equi-angular as possible and it is not affected by the order of observational points considered.

Triangulation offers several advantages as opposed to grid-based interpolation methods. First, when the surfaces have significant relief features, triangulation generates more accurate surfaces. This is because the triangulation maintains breakline features such as stream channel, ridges, and shorelines, and relief features such as peaks and pits. Second, triangulation is an exact method since original data points are located exactly on the surface. Finally, triangulation is faster in terms of computing time because it can efficiently represent the same surface as grid-based methods, but with fewer data points. The main disadvantage is that the surfaces are not smooth and may give a jagged appearance; discontinuous slopes at the triangle edges and data points cause the distorted appearance. In addition, triangulation is generally not suitable for extrapolation beyond the domain of observed data points (Hu, 1995).

II.3 Multicriteria Decision Analysis

Multicriteria decision making (MCDM) problems involve a set of attributes that are evaluated on the basis of conflicting and uncommensurate criteria. Two classes of MCDM can be distinguished: multiattribute and multiobjective decision making. Conventional MCDM techniques have been largely aspatial in the sense that they assume a spatial homogeneity within the study area (Malczewski, 1999). This assumption is
unrealistic in most decision-making situations because the evaluation criteria will vary across a studied area. The use of GIS for performing multicriteria decision analyses is instrumental for producing a representation of the spatial variation in MCDM. GIS capabilities such as data acquisition, storage, retrieval, manipulation, and analysis can be integrated with MCDM techniques and decision maker's preferences. The aggregation of these techniques and data sets can yield unidimensional values of alternative decisions.

II.3.1 Multiobjective versus Multiattribute Analysis

Criteria are the standards of judgment or rules on the basis of which the alternative decisions are ranked according to their desirability (Malczewski, 1999). Criterion is a generic term including concepts of attribute and objective; therefore, MCDM includes both multiobjective and multiattribute decision making. Attributes can be defined as measurable quantities of a geographical entity or a relationship between geographical entities. The concept of attribute is synonymous with the measurement of the system performance, and is used to measure performance in relation to an objective. An objective is a statement about the desired state of the system under consideration. Objectives are functionally related to, or derived from, a set of attributes (Malczewski, 1999). For any given objective, several different attributes may be necessary to determine to degree to which the objective might be achieved.

Multiobjective Decision Making (MODM) approaches involve designing the alternatives and searching for the “best” decisions among a very large set of alternatives.
They provide a framework for designing a set of alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions. Multiattribute decision problems require that choices be made among alternatives described by their attributes. The set of attributes is given explicitly and is used as both decision variables and decision criteria.

An attribute is a concrete descriptive variable while an objective is a *more* abstract variable with an interest in the relative desirability level of that variable. Multiattribute Decision Making (MADM) problems are assumed to have a predetermined, limited number of alternatives. Solving an MADM problem is a selection process, as opposed to a design process (Malczewski, 1999). The MODM problem is continuous in the sense that the best solution may be found anywhere within the region of feasible solutions. As a result, MADM and MODM problems are sometimes referred to as discrete and continuous decision problems, respectively. Table II.3.1 provides a comparison of MODM and MADM approaches.
Table II.3.1 Comparison of MODM and MADM approaches

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<td>Criteria defined by:</td>
<td>Objectives</td>
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<td>Objectives defined:</td>
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<td>Attributes defined:</td>
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<td>Constraints defined:</td>
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<tr>
<td>Alternatives defined:</td>
<td>Implicitly</td>
<td>Explicitly</td>
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<tr>
<td>Number of alternatives</td>
<td>Infinite (large)</td>
<td>Finite (small)</td>
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<tr>
<td>Decision maker's control</td>
<td>Significant</td>
<td>Limited</td>
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<tr>
<td>Decision modeling paradigm</td>
<td>Process-oriented</td>
<td>Outcome-oriented</td>
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<td>Relevant to:</td>
<td>Design/search</td>
<td>Evaluation/choice</td>
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<td>Relevance of geographical data structure</td>
<td>Vector-based GIS</td>
<td>Raster-based GIS</td>
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The MADM approach assumes that the set of alternatives is specified explicitly. The alternatives are represented by the set of cells in a raster GIS. In a particular decision situation, the set of alternatives can be limited by imposing constraints on the attribute values or locations. Given the input, the problem is to aggregate the map layers according to a decision rule so that the “best” alternative can be selected. The performance of an alternative depends on the level of the attribute by which the alternative is characterized. It also involves the decision maker's preferences with respect to the evaluation criteria.

Unlike MADM approaches, MODM methods make a distinction between the decision variables and the decision criteria. The alternatives are implicitly defined rather than given explicitly. From the MODM perspective, the attributes can be viewed as
information sources available to the decision maker. Consequently, the input data to
spatial MODM problems can be stored in a GIS in the form of map layers. Each map
layer contains a set of objects that are considered as elements of an alternative.

II.3.2 Framework

Decision making involves a sequence of activities that starts with problem
identification and ends with recommendations. It is argued that the quality of the
decision making depends on the sequence in which activities of the process are
organized. According to Keeney (1992), two major approaches exist: the alternative-
focus and the value-focused approaches. The alternative-focus approach focuses on
generating decision variables, while the value-focused approach uses evaluation criteria
as the fundamental element of the decision analysis. Comparison of the two approaches
shows that the differences are related to the question whether alternatives should be
generated first and then the value structure should be specified, or if the alternatives are
derived from the value structure. The elements of the framework based on the value-
focused approach are briefly discussed below.

As mentioned, the decision-making process begins with the recognition and
definition of the decision problem. The decision problem is a perceived difference
between the desired and existing states of a system (Malczewski, 1999). It is a “gap”
between the desired and existing states as viewed by a decision maker. Once the decision
problem is identified, the spatial multicriteria analysis focuses on the set of evaluation
criteria. This step involves specifying a comprehensive set of objectives and measures for achieving those objectives. The measures are called attributes in which a scale is determined for each.

The evaluation criteria are associated with geographical entities and can be represented in the form of criterion maps: evaluation and constraint maps. An evaluation criterion map is a unique geographical attribute of the alternative decisions used to evaluate the performance of alternatives (Malczewski, 1999). A constraint map displays the limitations on the value that attributes and decision variables may assume.

At this point, the decision maker's preferences (with respect to the evaluation criteria) are incorporated into the decision model. Preferences are typically expressed by the weights of relative importance assigned to evaluation criteria. The derivation of criterion weights is a central step in incorporating the decision maker's preferences (Malczewski, 1999). All preceding steps including the unidimensional measurements and preferences are then brought together using a decision rule or aggregation function. It is the decision rule that dictates how to best rank alternatives or decide which alternative is preferred over another.

The end result of a decision-making process is a recommendation for future action. The recommendation should be based on the ranking of alternatives. It may include a description of the best alternative or a group of alternatives. Visualization techniques are of major importance in presenting and communicating the results of the analyses performed.
CHAPTER III
THEORY AND METHODOLOGY

III.1 Data Acquisition

Data utilized during the conduction of this research would not have been processed without the use of GIS. The majority of the data was obtained in digital format with the ability for integration into a GIS. The USGS' GIS support center website provided supplemental information including hypsography, hydrography, boundary and transportation data. Data were then converted into a recognizable format, known as a shapefile, to be used in ArcView 3.2. The conversion was accomplished using an Avenue script, dlg2shape.ave (Bayes 2000).

The United States Army Corps of Engineers (USACE) provided data pertaining to the normal and record pool elevations of the Charles Mill Lake. These values were later used as boundary conditions for the steady flow analysis performed on the incoming reach of the Charles Mill Lake. Data recorded using a sonar GPS survey and conducted by the USACE in 1998 were the input for the generation of the digital elevation model (DEM) of Charles Mill.

The Muskingum Watershed Conservancy District (MWCD) provided the information pertaining to the land use surrounding Charles Mill, with a full description of its dredging procedures and methodologies for choosing potential disposal sites. A
detailed digital map displaying land use patterns, proposed dredging channels, and disposal sites were provided as a *.dwg file.

The final set of data utilized for this project was from results of the sediment sampling performed by Bayes (2000). The sampling involved the use of a gravity corer and a Global Positioning System (GPS). Samples were taken based on the known fact that the northern portion of the lake has accumulated more sediment. A higher concentration of samples was also taken at a location where more changes in sediment make-up were expected. A total of sixty-one samples were collected. The samples were first analyzed by inspection according to color, texture and approximate grain size. Once in the laboratory, the samples were dried and a sieve analysis was performed on each. The results of the analysis were used to produce soil gradation graphs where a best-fit curve was drawn (Bayes 2000). From the distribution curves, the percent of gravel, sand and silt were determined and entered into a text file later to be added to the sample’s database using the GIS. Figure III.1.1 shows the location of each sample collected from the Charles Mill Lake.
Charles Mill Lake

- Roads
- Hydrography
- Sample Locations
- Charles Mill Lake

Figure III.1.1 Sample Locations within Charles Mill Lake in 1998 (Bayes)
III.2 Evaluation Criteria

According to the information provided by the MWCD, quantifiable and nonquantifiable criteria are used when choosing disposal sites for the development of wetlands. Some of these criteria include adjacent land use, lake bottom characteristics, water depth, various wildlife habitat issues, distance from the dredging area, and materials to be dredged. This study focused on those criteria which have sufficient data for analysis. The criteria evaluated include water depth, sediment composition, adjacent land use, distance from the dredging operation, and distance from unsuitable land use types. Each criterion was derived from the information provided by the aforesaid sources and compiled using spatial modeling techniques within ArcView GIS. The methodology behind the derivation of each criterion is explained in the subsequent sections of this chapter.

III.2.1 Lake Bathymetry

By utilizing the DLG data obtained from the USGS, such data as county boundaries, surrounding topography, streams and roads could be extracted and then incorporated into the project GIS. As mentioned earlier, the data were converted into a series of shapefiles using an Avenue script. The boundaries of the Charles Mill Lake were isolated from the stream and also from the contour data, allowing for the delineation of the lake. The pool levels obtained from the USACE were then added to the database.
resulting in a newly created lake shapefile. The spatial modeling was performed in this analysis using raster algebra. As a result, any polygon shapefiles included in the analysis had to be converted into a network of cells (grids). A grid of the lake was created containing thousands of individual cells called rasters. Each raster was assigned the value of the mean summer pool; 304.061m.

In order to assess the variation in water depth throughout Charles Mill a Digital Elevation Model (DEM) was created. The GPS sonar data obtained from the USACE contained more than 52,000 individually surveyed data points. These points were interpolated to generate the bathymetric surface of the lake. The spline tension method was used as the interpolation model for the DEM production. As mentioned earlier, the spline method fits a minimum-curvature surface through input points. Conceptually, it is like bending a sheet of rubber to pass through the points while minimizing the total curvature of the surface (ESRI, 1996). A raster cell size of two meters was used throughout the entire project. This allowed for a more detailed analysis, which produced a better image with reduced errors. The resulting bathymetric surface of the lake is shown in Figure III.2.1.

Raster algebra was then used to generate an image depicting the variation of water depth throughout the lake. To produce the image, the 1998 DEM was used in conjunction with the lake grid set at the mean summer pool elevation. Figure III.2.2 displays the variation of water depth throughout the Charles Mill Lake.
Figure III.2.1 Bathymetric map of the Charles Mill Lake
Figure III.2.2 Variation in water depth within the Charles Mill Lake
The overall goal of this criterion is to minimize the water depth. This is to ensure that the chosen disposal sites will be designed as single-use sites by allowing for a better prediction of site life; it will also aid in minimizing future environmental impacts. The Charles Mill Reservoir is regulated and drawn down significantly in the winter. Because the focus of the dredging operation is to both improve navigation and enhance park and residential recreation facilities, the mean summer pool level was chosen as the primary water surface elevation. Though the winter pool level would produce lower water levels, it would not help to meet the purpose of this operation.

Only the raster cells along the interior and bordering shorelines of the lake were considered for the final analysis. This was done to limit the extent of the model to include all available data sets, because only onshore disposal practices are considered for this project. In order to segregate the desired raster cells, a buffer 10m wide that emanated from both sides of the Charles Mill shoreline was created. The width of 10m was selected in order to enlarge the model area for displaying purposes. Figure III.2.3 illustrates the methodology conducted within the GIS.
Figure III.2.3 Schematic diagram of lake bathymetry and depth criteria
III.2.2 Dredged Channels / Sediment Volume

The digital maps obtained from the Muskingum Watershed Conservancy District depicted both the current and proposed locations where the dredging had taken or might take place. The channels are between 60 and 75 feet wide and are in areas where sediment had accumulated most. These preexisting and proposed channels served as the dredged channels to be used in the spatial model and for sediment volume determinations.

The data received from MWCD was in the form of a *.dwg file or AutoCAD drawing. In order to import the drawings into ArcView GIS, the lake shapefile was brought into AutoCAD Map and was displayed at its coordinate projection within ArcView. The MWCD drawings were then overlayed onto the lake shapefile and then exported from those coordinates into ArcView. This allowed all data layers within the drawing to be placed into their correct geographic location. The dredged channels and disposal areas determined by MWCD were digitized and saved as shapefiles. Figure III.2.4 shows the current and proposed dredged channels.

Another criterion for determining the optimal location of dredged materials is the distance evaluation (or value) from the dredged channels to all areas along the shores of Charles Mill. The dredging equipment currently used by MWCD incorporates a 10-inch (25.4 cm) pressure pipe that serves as the means of transport for the dredged materials. The maximum length of the transport line is 2,500 ft. or 762 m. To assess this, buffers emanating from the channels were created to a maximum distance of 800 m.
Dredging Operation

Roads

- Charles Mill Lake
- Dredged Channels

Figure III.2.4 Dredged channel locations within the Charles Mill Lake (MWCD)
Raster algebra was then used to restrict the distance buffers originating from the dredged channels to the buffer grid created around the lake shoreline.

As an aid in the design and preliminary sizing of wetlands it is essential to know the volume of sediment to be dredged. The methodology discussed in this study is a means of achieving rough estimate of the volume of dredged sediment. Numerous soil parameters are required to properly determine bulking and consolidation/settling rates. No data pertaining to those parameters was available for this research. As a result, effects of bulking during dredging and transport were neglected.

To acquire an estimate of the volume of dredged materials, the desired depth for the lake, 1.5 m, was added to the dredged channel shapefile database. A script was then run to calculate the areas of all the dredged channels. Subsequently, the channel polygons were converted to grids, and the lake DEM was subtracted from the dredged channel grid. This produced the depth of sediment to be removed in order to achieve a desired water depth of 1.5 m within the channel. A query was performed to determine the mean sediment depth to be removed. Multiplying the total channel surface area by the mean sediment depth produced an estimate of the volume to be removed. Figure III.2.5 is a schematic diagram showing the procedure previously described.
Figure III.2.5 Schematic diagram of dredging distance and sediment volume
III.2.3 Land Use

The land use for the areas adjacent to the Charles Mill Lake was acquired and converted in the same manner as the dredged channels as described earlier. Various land uses were delineated and labeled accordingly. Figure III.2.6 displays land uses for Charles Mill and its surrounding area. According to MWCD, certain land use patterns are deemed unsuitable for dredged material disposal and wetland development. These land uses include residential, park, commercial, and protected areas. To exclude undesired land uses, the land use polygons were converted to grids and reclassified. The reclassified unsuitable land uses were then used in conjunction with the lakeshore buffer grid. This was done to maximize the distance from the unsuitable land use types in order to minimize impacts to the developed wetlands.

By maximizing the distance from undesired land uses, any wetlands that are created have less of a chance of being impacted by human intervention. This rationale led to the development of the next criterion. Once the undesired land uses had been identified, distances buffers were created emanating from the land uses patterns. The resulting buffers were then used to produce a map depicting the variation in distances from unsuitable land uses along the Charles Mill shoreline. The procedure for determining these two criteria is displaying in Figure III.2.7.
Figure III.2.6 Land use patterns for Charles Mill Lake (MWCD)
Land use patterns not suitable for shoreline unsuitable for wetland development based on local land use patterns,

**Evaluation Criteria #3**

**Distance buffers emanating from lake shoreline**

**Map depicting variation in distance from unsuitable land use patterns along shoreline, Evaluation Criteria #4**

**Distance buffers emanating from unsuitable land use patterns**

**Map depicting areas along shoreline unsuitable for wetland development based on local land use patterns, Evaluation Criteria #3**

**Figure III.2.7** Schematic diagram of land use distance and unsuitable land uses
III.2.4 Sediment Classification / Distribution

The location of a new wetland depends on many factors; one, in particular, is the substrate for which the wetland is to be developed. Sandy dredged material has been found to be an ideal substrate (Herbich, 2000). High current energies may not only prevent the formation of a stable substrate, but also eliminate vegetation. These conditions may force the use of protective structures. Hydraulically placed silt will usually require temporary or permanent containment, regardless of wave or current conditions. Sand is more likely to require little or no protection under low-energy situations. While sandy substrates can often be graded to achieve a desired slope and elevation, very fine-textured material cannot be easily modified once in place.

Given these considerations, the final criterion evaluated for this study is the maximization of the content of sand within the existing substrate of Charles Mill. The grain-size distribution curves produced by Bayes (2000) were used to determine the composition of the samples. The content levels of gravel, sand and silt were entered into a spreadsheet and then imported into the theme database of the sediment sample shapefile. In order to generate a geographic representation of the sand content for the lake substrate, the tension method of the spline model was used for the spatial interpolation. Since the data points were distributed evenly, the surface of the sediment deposits was assumed to be smooth (Mitas and Mitasova, 1988). Figure III.2.8 shows the distribution of sand throughout the Charles Mill Lake. Figure III.2.9 is a schematic diagram illustrating the methodology implemented within the GIS.
Figure III.2.8 Distribution of the percent of sand in the Charles Mill Lake
Figure III.2.9 Schematic diagram of sand content
III.3 Criterion Weighting

As mentioned, in the framework for multicriteria decision analysis, criterion weighting serves as an important role by incorporating the decision maker's preferences. As a result, information about the relative importance of the involved criteria is considered. The level of importance is typically determined by assigning a weight to each criterion. A weight can be defined as a value assigned to an evaluation criterion that indicates its importance relative to other criteria under consideration (Malczewski, 1999). The larger the applied weight, the more important the criterion is relative to other criteria. Typically, the weights of all criteria that are being considered sum to a value of 1. By assigning weights to evaluation criteria, the decision maker can account for both the changes in the range of variation for each evaluation criterion, and the different degrees of importance attached to these ranges of variation (Kirkwood, 1997). Different types of weighting procedures are available in terms of accuracy, degree of ease in use, understanding on the part of the decision makers, and theoretical foundation. The weighting methods investigated in this study include ranking, rating and the pairwise comparison methods.

The simplest method for assessing the importance of weights is to arrange them in rank order. In other words, every criterion is weighted in the order of the decision maker's preference. Three approaches for the ranking method are applied: the rank sum, rank reciprocal, and rank exponent.
Ranking methods of criteria weight determination, however, involve no underlying theory behind their application. Therefore, the methods are easy to apply, but the results may not be very trustworthy.

Rating methods require the decision maker to estimate weights based on a predetermined scale. Scales ranging from 0 to 100 are typically used. Two common approaches for the rating method are the point allocation and ratio estimation methods. The point allocation approach is based on allocating points ranging from 0 to 100. The more points a criterion receives, the greater its relative importance. The amount of points assigned to each criterion is divided by a value of 100 to yield a ratio, which serves as the weights for the criteria.

The ratio estimation is a modification of the point allocation approach. It uses ranking to identify the significance of the criterion. The most important criterion is assigned a score of 100, while smaller weights are assigned to the criteria lower in the order. The score for the least important criteria is divided by the scores of the other criterion. This ratio expresses the relative significance of a change from the worst level of the criterion to its best value. Once this procedure has been completed for each criterion, the normalized weights are determined.

The pairwise comparison method, on the other hand, was developed in the context of the analytic hierarchy process (AHP) by Saaty (1980). This method utilizes pairwise comparisons to create a ratio matrix. The weights developed in this method are determined by normalizing the eigenvector associated with the maximum eigenvalue of the ratio matrix.
This method is a system of three steps:

1. Development of the pairwise comparison matrix;
2. Computation of the criterion weights;
3. Estimation of the consistency ratio.

Development of the comparison matrix is based on a scale with values ranging from 1 to 9 that rates the preferences between two criteria. The scale for these values is shown below in Table III.3.1.

**Table III.3.1 Scale for pairwise comparison**

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
</tr>
<tr>
<td>2</td>
<td>Equal to moderate importance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
</tr>
<tr>
<td>4</td>
<td>Moderate to strong importance</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
</tr>
<tr>
<td>6</td>
<td>Strong to very strong importance</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
</tr>
<tr>
<td>8</td>
<td>Very to extremely strong importance</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
</tr>
</tbody>
</table>

The scores for the pairs of each criterion are placed in the upper right corner of the pairwise comparison matrix. This matrix consists of the factor criterion placed along the first column and first row so that each criterion may be compared with one another. The
pairwise comparison matrix is assumed to be reciprocal, meaning the values listed in the lower left corner of the matrix are the reciprocal of those from the upper right corner. Since a factor compared to itself it is of equal importance, the entries of the diagonal are all 1.

The first operation in computing criterion weights involves the summation of the values in each column of the matrix. Each element in the matrix is then divided by its column total to produce a normalized pairwise comparison matrix. The elements in each row of the normalized matrix are then averaged to determine weights for the criteria compared.

An important feature of the pairwise comparison method is that it takes into account the consistency of the comparisons performed. The eigenvector of the normalized matrix is calculated and used in determining the consistency index, which is a measure of departure from consistency. The consistency index is divided by the random index to calculate the consistency ratio. The random index is the consistency index of a randomly generated pairwise comparison matrix. The consistency ratio is designed so in the event that the ratio has a value less than 0.1, there is an allowable level of consistency in the pairwise comparison. If the consistency ratio is greater than or equal to 0.1, there is inconsistency in the weighting procedure and the intensity of importance values assigned in the original pairwise comparison matrix must be revaluated.
III.4 Multiattribute Decision Rules

The main elements of spatial multicriteria decision analysis are combined to meet the ultimate aim of the analysis using decision rules. The decision rules provide the basis for ordering the decision alternatives and for choosing the most preferred alternative. A decision rule is a procedure that allows for ordering alternatives (Starr and Zeleny, 1977). It integrates the data involving alternatives and decision maker's preferences into an overall assessment of the alternatives. The decision rule orders the decision space by means of a one-to-one or a one-to many relationship of outcomes to decision alternatives (Malczewski, 1999).

Spatial multiattribute methods are based on the assumption that the attributes serve as both decision variables and objectives. The aim of multiattribute decision making (MADM) analysis is to choose the best or the most preferred alternative. Many decision rules exist for handling the MADM problem. Additive decision rules are the best-known and most widely used MADM methods in GIS-based decision making (Malczewski, 1999). Three additive methods were investigated for this study: value/utility function approaches, the analytic hierarchy process and the simple additive weighting method.

The utility function method is based on multiattribute utility theory (Keeney and Raiffa, 1976). The term “utility” includes both the concepts of utility and value functions. The value function of the method assumes that the attributes are known with certainty. The utility function procedure incorporates the decision maker’s attitude into
the assessment of a single-attribute utility function. The value/utility methods indicate that it is quite difficult or impossible to obtain a mathematical representation of the decision maker's preferences for two reasons. First, the procedures for assessing utility functions with even a moderate number of criteria can be very time consuming and tedious. Second, the value/utility approach places considerable information-processing demands on the decision maker.

The analytic hierarchy process (AHP) procedure involves three major steps. The first step is to decompose the decision problem into a hierarchy that consists of the important elements of the decision problem. The decision elements are then compared on a pairwise base. The final step is to aggregate the relative weights of the levels obtained in the second step to produce composite weights. The composite weights represent ratings of alternatives with respect the overall goal with the most preferred alternative being identified by the maximum value of the composite weights. This method has been criticized for the ambiguity in the meaning of the relative importance of one element in the decision hierarchy when it is compared to another element.

Simple additive weighting (SAW) methods are the most often used techniques for tackling spatial multiattribute decision making. Also referred to as weighted linear combination (WLC) or scoring methods, they are based on the concept of a weighted average. Evaluation criteria are weighted based on relative importance. A total score is obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled/standardized value given to the alternative on that attribute, and summing the products over all attributes (Malczewski, 1999). The alternative with the
highest overall score is the most preferred. The decision rule evaluates each alternative by the following formula:

$$A_i = \sum_j w_i x_{ij}$$  \hspace{1cm} (III.4.1)

where $A_i$ indicates each alternative, $x_{ij}$ is the score of the $i$th alternative with respect to the $j$th attribute, and the weight $w_i$ is a normalized weight, so that $\sum w_i = 1$. The weights represent the relative importance of the attributes. The most preferred alternative is selected by identifying the maximum value of $A_i (i = 1, 2, \ldots, m)$.

The SAW methods can be implemented using any GIS system having overlay capabilities. The methods can be implemented in both raster and vector GIS environments. The steps involved in applying the GIS-based SAW method first begin by defining a set of evaluation criteria which are then standardized. Criterion weights are defined and assigned directly to each criterion map. Weighted standardized maps layers are then generated by multiplying the standardized maps by their corresponding weights. The overall scores for each alternative are then determined by adding the values of the weighted standardized map layers with the highest score indicating the best alternative. SAW methods are based on little theoretical foundation but their compatibility for GIS implementation; this may explain why they are so widely applied in real-world settings (Massam, 1988).
III.5 Flood Analysis Using GIS and HEC-RAS

AVRas version 2.2 is an ArcView GIS extension that prepares geospatial data for use with the Hydrologic Engineering Center River Analysis System (HEC-RAS). Version 2.2 of AVRas was developed by Djokic at the Environmental Systems Research Institute (ESRI) along with technical support from HEC staff (Evans, 1999). The extension is a collection of GIS pre- and post-processing tools which presents HEC-RAS results in a geospatial context (Ackerman, at el., 1999).

AVRas enables users to use ArcView GIS to develop HEC-RAS models integrated with digital terrain models and other GIS data sets. It allows for the generation of an HEC-RAS import file containing river geometry and model parameters from an existing digital terrain model (DTM). Shapefiles that define the stream network, cross-section locations and other hydraulic characteristics of the river system are also included within the import file. The import file is created from a DTM in the form of an ArcView triangulated irregular network (TIN) and a series of shapefiles defining features in the model.

HEC-RAS reads the import file and generates model geometry. The user is then required to complete the model geometry by supplying flows and boundary conditions for all the flow profiles to be calculated by HEC-RAS. Once the hydraulic calculations are completed, the user can export the results and use AVRas to generate grids and shapefiles to represent depths and inundated areas corresponding to the calculated flow profiles.
III.5.1 AVRas Application

To construct the geometry of an HEC-RAS river model for this study, AVRas requires the user to provide a series of inputs to complete the pre-processing phase. A TIN representing the land surface and shapefiles representing the stream centerline and the plan-view locations (cutlines) of the cross sections are required for the model. In addition, the user is required to provide shapefiles representing the locations of the stream banks, and in-channel and overbank flow paths. The following themes listed along with recommended formats are used to develop HEC-RAS geometry using AVRas.

- Digital terrain model (TIN)
- Stream centerline (line shapefile)
- Cross-section cutlines (line shapefile)
- Bank lines (line shapefile)
- Flow paths (line shapefile)

Developing a hydraulic model begins with an accurate geometric description of the surrounding landform, especially the channel geometry (Ackerman, 1999). Channel geometry normally dictates flow in river systems; therefore, only DTMs describing channel geometry with high accuracy and resolution should be considered for the basis of performing hydraulic analysis (Evans, 1999). All themes used in developing an HEC-RAS model should be created and edited with thoughtful evaluation of the river hydraulics that are governed by the terrain. It is crucial to the validity of the resulting
HEC-RAS model that the river network, flow paths, bank positions, and cross-section locations are consistent with the terrain model. Data imported to HEC-RAS from AVRas keep their 2D and 3D coordinates, so that a georeferenced model in HEC-RAS has a more map-like appearance than a non-georeferenced schematic. The coordinates preserved in HEC-RAS allow results from hydraulic simulations to be mapped in AVRas and incorporated into other GIS projects.

III.5.2 Water Surface Profile Computation

HEC-RAS is an integrated system of software designed for interactive use in a multi-tasking, multi-user network environment (HEC, 1997). The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The steady flow component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a single river reach, a dendritic system, or a full network of channels. The steady flow component is capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles.

The computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The
effects of various obstructions such as bridges, culverts, weirs, spillways and other structures in the floodplain may be considered in the computations. The steady flow system is designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments (HEC, 1997).

HEC-RAS utilizes an iterative process known as the standard step method for solving the energy equation to determine depth of flow. The computation is carried on by steps from station to station where the hydraulic characteristics have been determined. The energy equation is expressed in the following manner:

\[
Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_l
\]  \hspace{1cm} (III.5.1)

where \(Y_1, Y_2\) are the depths of water, \(Z_1, Z_2\) are the elevations of the main channel inverts, \(\alpha_1, \alpha_2\) are the kinetic energy correction factors, \(g\) is gravitational acceleration, and \(h_l\) is the head loss between cross sections 1 and 2. The terms of the energy equation are displayed in Figure III.5.1. The energy head loss between two cross sections is made up of losses due to friction and contraction or expansion. The head loss, \(h_l\), is estimated by HEC as:

\[
h_l = L\bar{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|
\]  \hspace{1cm} (III.5.2)
where, $L$ is the discharge weighted reach length, $\bar{S}_f$ is the representative friction slope between the two sections, and $C$ is the expansion or contraction loss coefficient.

![Figure III.5.1 Representation of Terms in the Energy Equation (HEC, 1997)](image)

The distance weighted reach length, $L$, is calculated from the following expression:

$$L = \frac{L_{lob} \overline{Q}_{lob} + L_{ch} \overline{Q}_{ch} + L_{rob} \overline{Q}_{rob}}{\overline{Q}_{lob} + \overline{Q}_{ch} + \overline{Q}_{rob}}$$  \hspace{1cm} (III.5.3)$$

where $L_{lob}, L_{ch}, L_{rob}$ are the cross section reach lengths specified for flow in the left overbank, main channel, and right overbank, respectively, and $\overline{Q}_{lob}, \overline{Q}_{ch}, \overline{Q}_{rob}$ are the arithmetic averages of the flows between sections for the left overbank, main channel, and right overbank, respectively.
In order to determine the total conveyance and the velocity coefficient for a cross section, the flow must be subdivided into units for which the velocity is uniformly distributed (HEC, 1997). HEC-RAS does this by dividing the flow into areas where Manning’s \( n \) changes. Figure III.5.2 displays a diagram of the conveyance subdivision method.

![Diagram of the conveyance subdivision method](HEC, 1997)

**Figure III.5.2** Diagram of the conveyance subdivision method (HEC, 1997)

Conveyance is then calculated within each subdivision using the following form of Manning’s equation:

\[
Q_i = K_i S_f^{1/2} \tag{III.5.4}
\]

where \( K_i \) is estimated by

\[
K_i = \frac{1.486}{n} A_i R_i^{2/3} \tag{III.5.5}
\]
where $K_i$ is the conveyance for subdivision $i$, $n_i$ is Manning's $n$ value for subdivision $i$, $A_i$ is the flow area for subdivision $i$, and $R_i$ is the hydraulic radius for subdivision $i$. The incremental conveyances within the overbanks are summed up to obtain a conveyance for the left and right overbanks. Then the three conveyances (left, channel, and right) are summed to obtain a total conveyance for the cross section.

Flow in the main channel is only subdivided when the roughness coefficient is changed within the channel area. HEC-RAS determines if the main channel can be subdivided by evaluating two criteria. A composite roughness $n_c$ will be computed if the main channel slope is steeper than 5:1 and the main channel has more than one $n$-value. The determination of the composite roughness coefficient is obtained by the following expression (Chow, 1959):

$$n_c = \left[ \frac{\sum_{i=1}^{n} P_i n_i^{1.5}}{P} \right]^{2/3} \quad (\text{III.5.6})$$

where $n_c$ is the composite or equivalent Manning's $n$ value, $P$ is the wetted perimeter of entire main channel, $P_i$ is the wetted perimeter of subdivision $i$, and $n_i$ is the coefficient of roughness for subdivision $i$.

Since HEC-RAS is a one-dimensional water surfaces profiles program, evaluation of the mean kinetic energy head involves computing a single mean energy at each cross section. In order to calculate the mean kinetic energy, the velocity head weighting
coefficient, $\alpha$, is computed. It is written in terms of conveyance and area shown in Equation III.5.7:

$$\alpha = \frac{(A_t)^2 \left[ \left( \frac{K_{lob}}{A_{lob}} \right)^2 + \left( \frac{K_{ch}}{A_{ch}} \right)^2 \right] + \left[ \left( \frac{K_{rob}}{A_{rob}} \right)^2 \right]}{(K_t)^3} \quad \text{(III.5.7)}$$

where $A_t$ is the total flow area of the cross section, $A_{lob}$, $A_{ch}$, $A_{rob}$ are the flow areas of the left overbank, main channel, and right overbank, respectively, $K_t$ is the total conveyance of the cross section, and $K_{lob}$, $K_{ch}$, $K_{rob}$ are conveyances of the left overbank, main channel, and right overbank, respectively.

Losses due to friction are determined in HEC-RAS as the product of the representative friction slope, $\bar{S}_f$, and the discharge weighted reach length, $L$ (HEC, 1997). The friction slope (slope of the energy gradeline) is determined at each cross section by the following expression:

$$S_f = \left( \frac{Q}{K} \right)^2 \quad \text{(III.5.8)}$$

where $S_f$ is the friction slope, $Q$ is the discharge, and $K$ is the conveyance at the cross section. Losses due to contraction and expansion are evaluated in HEC-RAS by the following expression:
where $C$ is the contraction or expansion coefficient, and $h_0$ is the contraction and expansion head losses. HEC-RAS assumes that a contraction is occurring whenever the velocity head downstream is greater than the velocity head upstream. The same is true for the opposite case when the upstream head is greater than that of the downstream, except a flow expansion is assumed. As mentioned earlier, the unknown water surface elevation at a cross section (station) is determined by an iterative solution of the energy equations. The computational procedure for determining unknown water surface elevations is as follows:

1. Assume a water surface elevation at the upstream cross section for a subcritical computation, and downstream cross section for a supercritical computation.
2. Based on the assumed water surface elevation, determine the corresponding total conveyance and velocity head.
3. Using values from step 2, compute $\bar{S}_f$ and $h_e$ by Equation III.5.2.
4. Using values from steps 2 and 3, solve Equation III.5.1 for the new water surface elevation at section 2.
5. Compare the computed water surface elevation with that assumed in step 1; repeat step 1 through step 5 until the values match each other within 0.01 feet (0.003 m), or within the user defined tolerance.

\[ h_0 = C \left| \frac{\alpha_1 V_1^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right| \]  

(III.5.9)
III.5.3 Floodplain Delineation

Once all flow computations have been completed, HEC-RAS model results can be exported to a file read by AVRas. The file has a *.gis extension, and contains the locations of the cross sections, the stream centerlines, and, if desired, the ground points along the cross sections. Water surface elevations for all exported profiles are grouped with the cross section cut lines, along with bounding polygons of the modeled regions for each profile. AVRas performs no hydraulic calculations, but rather a series of steps are performed to complete the post-processing phase. A shapefile of the cross sections with water surface elevations for each exported profile is created. Next, a TIN of the water surface elevations for each profile, using the cross sections as breaklines is generated. The TIN is then clipped by the bounding polygons for the profiles. The ground-surface TIN and the water-surface TIN are then converted to grids. This is accomplished by subtracting the ground TIN from the water TIN to obtain a depth grid. Finally, a shapefile of inundated areas is created for each profile.

Since AVRas’s interpretation of HEC-RAS results is based entirely on geometry and not on hydraulics, it is advised to carefully check the depth and inundation boundary results carefully. A hydraulic model lacking a sufficient number of cross sections to define bends in the channel will produce poor mapping results outside the immediate vicinity of the cross sections (Evans, 1999). The results produced by AVRas should be regarded as a good start to a flood map.
CHAPTER IV
APPLICATION AND RESULTS

IV.1 Evaluation Criteria Generation

Five criteria were considered and evaluated in this study using the procedures described in the previous chapter. As mentioned earlier, only the raster cells along the interior and bordering shorelines of the studied lake were considered for the final analysis. The extents of all five criteria were so arranged to include all available data sets.

For the model to function effectively, its extents must be completely occupied by the raster cells of the five criteria. Any cells within the model that do not contain information from each of the five criteria will be eliminated from the model results with "no data" value. This serves as a preliminary screening for the model. For instance, four of the five criteria considered in this study were completely included within the extents of the model. The unsuitable land use criterion was partially eliminated because its boundaries extended outward only as far as the lake shoreline. Criteria, such as the sand content and water depth that extended to the shoreline from the interior of the lake were also excluded. As a result, these three criteria did not completely overlap. To remedy this problem, the boundaries of the original land use types were extended into the lake to meet the interior boundary of the model.

Given varied scales that attributes can be measured on, multicriteria decision analysis requires that the values contained in the various criterion map layers be
transformed to comparable units (Malczewski, 1999). This was the next step to be performed in the study. Varied approaches are available to make criterion map layers comparable. Linear scale transformation as the most frequently used method for transforming input data into commensurate criterion maps was chosen for this study. The maximum score and score range procedures are often used for linear scale transformation.

One of the easiest means for standardizing raw data is to divide each raw score by the maximum value for a given criterion as shown in the following:

\[
x'_{ij} = \frac{x_{ij}}{x_{j}^{\text{max}}}
\]

or

\[
x'_{ij} = 1 - \frac{x_{ij}}{x_{j}^{\text{max}}}
\]

where \(x'_{ij}\) is the standardized score for the \(i\)th (alternative) and the \(j\)th attribute, \(x_{ij}\) is the raw score, and \(x_{j}^{\text{max}}\) is the maximum score for the \(j\)th attribute. The value of the standardized scores can range from 0 to 1 with a higher score indicating the most desirable criterion value. If it is required that the criterion be maximized, Equation IV.1.1 is used while Equation IV.1.2 is to minimize the criterion. An advantage to this method is that it makes proportional transformation of raw data. As a result, the relative order of magnitude of standardized scores remains equal. On the other hand, the lowest
standardized value does not necessarily equate to zero, and makes the interpretation of the least attractive criterion score difficult.

An alternative for the linear transformation method is the score range procedure, expressed in following:

\[
x'_{ij} = \frac{x_{ij} - x_{i}^{\text{min}}}{x_{j}^{\text{max}} - x_{j}^{\text{min}}}
\]

or

\[
x'_{ij} = \frac{x_{j}^{\text{max}} - x_{j}^{\text{min}}}{x_{j}^{\text{max}} - x_{j}^{\text{min}}}
\]

where \( x'_{ij} \) is the standardized score for the \( i \)th (alternative) and the \( j \)th attribute, \( x_{ij} \) is the raw score, \( x_{j}^{\text{max}} \) is the maximum score for the \( j \)th attribute, \( x_{j}^{\text{min}} \) is the minimum score for the \( j \)th attribute, and \( x_{j}^{\text{max}} - x_{j}^{\text{min}} \) is the range of a given criterion. Values of the standardized scores range from 0 to 1 with the highest value indicating the most attractive criterion value. Equation IV.1.3 is for the maximization of the criterion, and Equation IV.1.4 is for the minimization. The major advantage of this procedure is that the scale of measurement varies precisely between 0 and 1. This method of standardization was chosen since the score range procedure does not produce proportional changes in the outcomes.

Standardization of the evaluation criteria was conducted by maximizing the values for the sand content and land use distance criteria. The water depth and dredge
channel distance criteria were minimized for the reasons aforesaid. The unsuitable land use criterion relied on Boolean logic for its standardization. In other words, unsuitable land uses were reclassified as 0 and preferred land uses as 1. Implementation of the linear scale transformation within the GIS was conducted by first deriving maximum and minimum value maps for a given criterion. The appropriate overlay operations were then performed whether or not the criterion was to be maximized or minimized. The following is a procedural example that applies the raw score method for the minimization of a given criterion.

The minimum value map is subtracted from the maximum value map to obtain the range map layer. The raw data map is then subtracted from the maximum value map to obtain the "maximum" differences map. Finally, the differences map is divided by the range map. Figure IV.1.1 is a schematic diagram for minimization of the linear scale transformation approach.

Figure IV.1.1 Schematic diagram of the linear transformation approach for criterion standardization
IV.2 Weighting Analysis

The pairwise comparison method was the process used for determining the criteria weights in the study. As discussed previously, the weights developed in this method are determined by normalizing the eigenvector associated with the maximum eigenvalue of the ratio matrix. The method is broken down into steps: development of the pairwise comparison matrix, computation of the criterion weights, and estimation of the consistency ratio. Evaluation of three weighting methods described in the previous chapter resulted in the selection of the pairwise comparison for this study. According to Malczewski (1999), it is based on statistical and heuristic theory, which makes it quite precise. Including the consistency ratio assists the decision process for selecting the appropriate level of importance for each criterion. This method has been tested theoretically and empirically for a variety of decision situations, including spatial decision making (Lai and Hopkins, 1995).

Development of the comparison matrix is based on a scale with values ranging from 1 to 9 to rate the preferences between two criteria. The scale used in this study is given in Table III.3.1. Development of the pairwise comparison matrix was initiated with information provided by the MWCD. The notion that any potential disposal site for wetland development cannot be placed within a residential, commercial, park or protected area was of the most importance. As a result, the land use criterion was valued as a higher level of importance than other criteria. It was also known that the distance from the dredging site plays an important role; the greater distances to which the dredged material has to be pumped, the greater the cost associated with the dredging operation.
The remaining criteria were compared against one another based on the pairwise comparison method and are shown below in Table IV.2.1.

**Table IV.2.1** Pairwise comparison matrix

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Land use</th>
<th>Distance from Dredging Operation</th>
<th>Water Depth</th>
<th>Distance from Unsuitable Land use</th>
<th>Sand Content of Lake Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Distance from Dredging Operation</td>
<td>1/3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Water Depth</td>
<td>1/5</td>
<td>1/2</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Distance from Unsuitable Land use</td>
<td>1/2</td>
<td>1/3</td>
<td>1/4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Sand Content of Lake Substrate</td>
<td>1/6</td>
<td>1/4</td>
<td>1/3</td>
<td>1/2</td>
<td>1</td>
</tr>
</tbody>
</table>

The summations of the values in each column of the matrix divided by its column total are then used to produce the normalized pairwise comparison matrix shown in Table IV.2.2.

**Table IV.2.2** Normalized pairwise comparison matrix

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Land use</th>
<th>Distance from Dredging Operation</th>
<th>Water Depth</th>
<th>Distance from Unsuitable Land use</th>
<th>Sand Content of Lake Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>0.455</td>
<td>0.590</td>
<td>0.583</td>
<td>0.190</td>
<td>0.375</td>
</tr>
<tr>
<td>Distance from Dredging Operation</td>
<td>0.152</td>
<td>0.197</td>
<td>0.233</td>
<td>0.286</td>
<td>0.250</td>
</tr>
<tr>
<td>Water Depth</td>
<td>0.091</td>
<td>0.098</td>
<td>0.117</td>
<td>0.381</td>
<td>0.188</td>
</tr>
<tr>
<td>Distance from Unsuitable Land use</td>
<td>0.227</td>
<td>0.066</td>
<td>0.029</td>
<td>0.095</td>
<td>0.125</td>
</tr>
<tr>
<td>Sand Content of Lake Substrate</td>
<td>0.076</td>
<td>0.049</td>
<td>0.039</td>
<td>0.048</td>
<td>0.063</td>
</tr>
</tbody>
</table>

1.000 1.000 1.000 1.000 1.000
With the completion of the normalized pairwise comparison matrix, the rows of the matrix were averaged, producing the weight for each criterion studied. The resulting weights can be interpreted as the average of all possible ways of comparing the criteria. The finalized weights used in the analysis are shown in Table IV.2.3.

**Table IV.2.3 Calculated criteria weights**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>0.439</td>
</tr>
<tr>
<td>Distance from Dredging Operation</td>
<td>0.223</td>
</tr>
<tr>
<td>Water Depth</td>
<td>0.175</td>
</tr>
<tr>
<td>Distance from Unsuitable Land use</td>
<td>0.108</td>
</tr>
<tr>
<td>Sand Content of Lake Substrate</td>
<td>0.055</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.000</strong></td>
</tr>
</tbody>
</table>

As a means of checking the consistency between the comparisons, an estimation of the consistency ratio was performed. According to Malczewski (1999), a reasonable level of consistency is concluded when the calculated consistency ratio is less than 0.10. If the consistency ratio is greater than or equal to 0.10, the values of the ratio are a possible example of inconsistent judgments. The final comparison values and weights determined for this study were the result of attempts to achieve a consistency ratio of less than 0.10. The procedure for determining the consistency ratio is described in the previous chapter. The results are shown in Table IV.2.4 and conclude that there is consistency between the comparisons with a consistency ratio of 0.027.
Table IV.2.4 Consistency ratio estimation

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Consistency Vector</th>
<th>Average of Consistency Vectors, λ</th>
<th>Consistency Index, CI</th>
<th>Consistency Ratio, CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use</td>
<td>5.766</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance from Dredging Operation</td>
<td>5.657</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Depth</td>
<td>5.561</td>
<td>5.123</td>
<td>0.031</td>
<td>0.027</td>
</tr>
<tr>
<td>Distance from Unsuitable Land use</td>
<td>3.221</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand Content of Lake Substrate</td>
<td>5.408</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IV.3 Multiattribute Decision Analysis

The simple additive weighting (SAW) method was applied as the means of evaluating areas along the shores of the Charles Mill Lake as potential disposal sites. The SAW method is known for its compatibility for GIS implementation, and is often applied in real-world settings. As discussed in Chapter III, the steps involved in applying the GIS-based SAW method first begin by generating a set of standardized evaluation criteria. The final criteria used in this study involved the variation of water depth, the content of sand within the substrate, the distance extending from the site of the dredging operation, adjacent land uses, and the distance extending from those land uses. The extents of each criterion were limited to the interior and bordering shorelines of the lake.

The evaluation criteria were standardized using the linear scale transformation method. Each map layer ranged in value from 0 to 1 with higher values indicating a
more attractive criterion. Criterion weights previously defined using the pairwise comparison method were then directly assigned to each criterion map. Weighted standardized map layers are then generated for each criterion by multiplying the standardized maps by the corresponding weights. Finally, the overall scores for each alternative were determined by adding the values of the weighted standardized map layers. The highest score is an indication of the most preferred alternative in terms of the five criteria evaluated. Figure IV.3.1 is a flowchart showing the simple additive weighting method as implemented within the GIS for the study.

Initial stages of the application of the SAW model produced invalid results. As discussed earlier, in order for the model to function effectively, its extents need to be completely occupied by the raster cells of the five criteria. During preliminary trials of operation, the majority of raster cells contained within the model were omitted. The unsuitable land use criterion was partially void because its boundaries extended outward only as far as the lake shoreline. As a result, only minimum numbers of cells overlapped within the model boundaries. The boundaries of the land use shapefile were altered to meet the boundary of the model by extending them to meet the remaining criteria.

Successful application of the model resulted in a range of values between 0.158 and 0.934. Values on the higher end of the scale indicate areas along the Charles Mill shoreline that are most suitable for dredged material disposal and wetland development. Figure IV.3.2 is the result once the model has been successfully applied. As shown in the diagram, red shoreline areas indicate regions that are favorable for disposal site locations.
Evaluation Criteria #1

|------------------------|------------------------|------------------------|------------------------|

Maximum and minimum value maps determined for each criterion

Standardized criterion maps based on linear scale transformation

Criteria weights determined from the pairwise comparison method

Weighted standardized criterion maps

Map depicting application of SAW method of spatial multiattribute decision-making. Highest values = most suitable rasters (locations) for disposal and wetland development

Figure IV.3.1 Multittribute decision analysis flow chart
Disposal Site Evaluation

Roads

Charles Mill Lake

0.158 - 0.236
0.236 - 0.313
0.313 - 0.391
0.391 - 0.469
0.469 - 0.546
0.546 - 0.624
0.624 - 0.701
0.701 - 0.779
0.779 - 0.857
0.857 - 0.934

0 0.4 0.8 1.2 1.6 Kilometers

Figure IV.3.2 Charles Mill Lake shoreline disposal site evaluation
A criterion with higher weight takes precedence over lower weighted counterparts. Optimal results as shown in Figure IV.3.2 occur when the distance from the local land use has been maximized, and the distance from the dredging operation has been minimized. This can also be confirmed by the results of the pairwise comparison method in Table IV.2.3, where the land use and the distance from dredging operation have greater weights than the remaining criteria.

The data obtained from MWCD include disposal sites of current and proposed dredging operations. By overlaying MWCD’s current and proposed disposal sites onto the model results, a comparison can be made. The results of the overlay show an agreeable coincidence between the locations of the model selections and the MWCD sites as given in Figure IV.3.3. The selected sites appear to be concentrated within the northern portion of the lake due to great weights of the land use and distance from dredging operation criteria. This can also be interpreted that they are located relatively close to the proposed dredge channels.

The preferred sites selected by the model are also focused around the interior shores (islands) of the lake. Experts at the MWCD have pointed out that utilizing areas surrounding existing islands for potential wetland sites decrease the chance for human intervention with wildlife and habitat development. The agreeable result of overlaying the MWCD proposed disposal sites onto their counterparts selected by the multiattribute decision analysis, as given in Figure IV.3.3, provides the confidence for the use of the developed model.
Figure IV.3.3 Comparison of SAW model results and MWCD proposed disposal sites
IV.4 Flood Inundation Due to Disposal Sites

The creation of wetlands for sediment disposal within man-made reservoirs results in the loss of storage capacity. The placement of such wetlands near or at the mouth of the incoming stream of the reservoir may change flood inundation areas. The results of the multiattribute decision analysis show that areas within the vicinity of the mouth have the potential to enclose disposal sites. To represent disposal site placement at or near the mouth of the Black Fork Creek, its cross section was constricted. To begin, the stream needs to be modeled in its natural state. The pre-processing phase of the AVRas extension was implemented to produce an input file for the HEC-RAS analysis. Development of the input HEC-RAS geometry file began by generating a series of themes representing the stream centerline, banks, and flowpath. First, the centerline of the stream was delineated using hydrography data obtained from the USGS. The banks and flowpath were also created in the same manner.

In an ideal situation, stream cross sections used in the study would be surveyed. The sonar survey data points collected by the USACE in 1998 were used to construct the stream cross-sectional geometry near the mouth for this study. Approximately 118 meters of elevation data upstream of the mouth were collected by the USACE. This data was used to determine the slope of the stream by extrapolating the elevations along the centerline.

The centerline theme was first converted into points by the use of an Avenue script. Then, the survey points were used to interpolate elevations for the newly converted centerline points. The distance between each point was then determined and
added to the centerline attribute table in ArcView GIS. The table can be opened in Excel to calculate changes in elevation between the points.

The cross sections were extended from the stream mouth upstream for 2.43 km. The final elevation for the centerline was considerably higher than the ground surface elevation at the furthest point upstream. The hypsography data were used to interpolate an estimated slope of the land leading up to the mouth of the stream. Combination of the data obtained from the USACE and the surrounding topography resulted in a slope of 0.002. This value was used to determine the elevations of the points along the centerline. The values were then merged back into the centerline attribute table within ArcView.

HEC-RAS requires cross section geometry to compute water surface profiles; therefore, cross sections and a terrain TIN were created for the model. AVRas uses the TIN to extract three-dimensional cross sections for the geometry input file. Each cross section was represented by a polyline and placed perpendicular to the direction of flow. To create the TIN, the contour lines within the extent of the study area were converted into points and combined with the stream centerline points. Figure IV.4.1 shows a portion of the cross sections locations and the TIN. Completing the pre-processing phase involved stationing the cross sections and the export of the centerline and 3-D cross sections. The input file was then saved as a *.geo file to be used for the HEC-RAS analysis.
Before any hydraulic flow computations can be performed, hydraulic parameters are added to the model. Manning’s roughness coefficients were required for both the channel and adjacent areas. Roughness coefficients are determined based on channel surface, vegetation, channel alignment, obstruction, stage and discharge, seasonal change, temperature, and suspended material (Chow, 1959). Values used in this study were selected according to the Woody Cowan’s method (Cowan, 1956) and roughness tables from the HEC-RAS reference manual (HEC-RAS, 1997).

In order to perform steady flow analyses using the standard step method in HEC-RAS, discharges and their corresponding stages are needed as initial conditions. Values that correspond to the four highest recorded flood stages and the summer pool elevation
were obtained from the USACE. These water surface elevations were used in the model, and their corresponding discharges calculated using Manning’s formula.

The cross sections within the geometry file were interpolated with the exception of the two cross sections closest to the mouth. Using the channel centerline, banklines, and surrounding area, studies have shown that the area of the cross section within the channel is insignificant when compared to the wet area during large flows (Shi, 2000).

The cross section at the mouth of the stream was generated from surveyed data. It closely resembled that of a trapezoidal channel. This cross section was constricted to simulate the presence of a disposal site near the mouth. A change in the geometry of the cross section leads to the recalculation of the water surface. To determine the water surface for a constricted cross section, the Manning’s formula was used.

Cross sections within the HEC-RAS geometry file can be modified, plotted and then exported as a *.dxs file. The cross section at the mouth was exported and opened in AutoCAD to draw the known water surface elevations. Both the wetted perimeter and cross sectional area for each water surface were determined and then used to calculate the discharges.

As a means of verifying the methodology and the value obtained for mean flow, the flood-peak discharges were determined for the Black Fork Creek. Multiple regression equations applicable for ungaged, rural, and unregulated streams in Ohio were utilized to calculate the discharges corresponding to various flood elevations (Koltun, 1990). The method was produced by the USGS, and is a function of channel slope, storage area, and contributing drainage area. The storage area represents the percentage of the contributing drainage area occupied by lakes, ponds and swamps; this value was
assumed to be zero. The channel slope and contributing drainage area were calculated using ArcView GIS. The contributing area for the Black Fork was delineated and estimated to be 195.42 sq. mi. The discharges calculated for the varying pool elevations are shown in Table IV.4.1.

Table IV.4.1 Initial discharges and their corresponding water surface elevations

<table>
<thead>
<tr>
<th>Record Date</th>
<th>Pool Elevation (ft.)</th>
<th>Pool Elevation (m)</th>
<th>Q (cms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/25/59</td>
<td>1013.53</td>
<td>308.924</td>
<td>7137.910</td>
</tr>
<tr>
<td>7/10/69</td>
<td>1010.90</td>
<td>308.122</td>
<td>4874.799</td>
</tr>
<tr>
<td>3/7/79</td>
<td>1010.46</td>
<td>307.988</td>
<td>4531.670</td>
</tr>
<tr>
<td>6/17/81</td>
<td>1007.69</td>
<td>307.144</td>
<td>2694.634</td>
</tr>
<tr>
<td>Summer Pool</td>
<td>997.00</td>
<td>304.061</td>
<td>51.107</td>
</tr>
</tbody>
</table>

According to Warren Viessman, the recurrence interval of the mean annual flood is about 2.33 years (1996). The mean flow value of 51.107 cms is below the 2-year flood discharge of 61.28 cms that was calculated using the USGS multiple regression method (Koltun, 1990).

The hydraulic analysis was performed on the non-constricted cross section of the Black Fork, and the results of the model were exported as a file with the extension *.gis. The file is composed of stream geometry and water surface elevations used by AVRas to create a water surface TIN. The TIN is then compared to the previously generated terrain TIN to delineate the floodplains for each of the corresponding discharges. To accomplish this, the post-processing portion of the AVRas extension is implemented. As an
example, Figures IV.4.2 through IV.4.4 show the inundated areas corresponding to the record pool level of the 1959 flood, and the mean summer pool elevation.

It is obvious that the 1959 record flood is considerably greater than the mean flow. By looking at the flow areas for these discharges, the record flood area is more than 50 times larger than the mean flow area. Table IV.4.2 shows the relationship between the flow areas for the record pools and the mean pool.

**Table IV.4.2 Flow area comparisons at record and mean pool levels**

<table>
<thead>
<tr>
<th>Record Date</th>
<th>Pool Elevation (m)</th>
<th>Flow area (m²)</th>
<th>Mean flow area / Record flow area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean flow</td>
<td>304.061</td>
<td>31.492</td>
<td>-</td>
</tr>
<tr>
<td>1/25/59</td>
<td>308.924</td>
<td>1341.648</td>
<td>2.35%</td>
</tr>
<tr>
<td>7/10/69</td>
<td>308.122</td>
<td>1054.443</td>
<td>2.99%</td>
</tr>
<tr>
<td>3/7/79</td>
<td>307.988</td>
<td>1007.538</td>
<td>3.13%</td>
</tr>
<tr>
<td>6/17/81</td>
<td>307.144</td>
<td>694.776</td>
<td>4.53%</td>
</tr>
</tbody>
</table>

Given that the record floods are about the same order of magnitude, what effect will reducing the original cross section have on the inundated area? Because the percentage of record flow areas is so minute, and the magnitudes of these flows are so large, it was assumed that the reduction of the cross section would have no effect on the inundated area. As a result, only the mean flow was used when constricting the cross section.
Figure IV.4.2 Inundated areas for 1959 flood
Elev
Mean Flow

Roads

Elevation Range
- 361 - 369 m
- 354 - 361 m
- 347 - 354 m
- 339 - 347 m
- 332 - 339 m
- 325 - 332 m
- 317 - 325 m
- 310 - 317 m
- 303 - 310 m

Figure IV.4.3 Inundated areas for mean flow
Figure IV.4.4 Comparison of inundated areas for 1959 flood and mean flow
Since the size and volume of a disposal site placed near the mouth of the stream is unknown, the cross section constriction was simulated by reducing the area on a percentage basis. As mentioned earlier, the constricted cross section is assumed to be trapezoidal. When reducing the area, the side slopes of the channel were held constant while the channel bottom and top width were altered. While the discharge and side slopes were held constant, an iterative process, developed with Excel, was used to calculate the water depth in order to meet the desired discharge. Table IV.4.3 shows the determined depths and their corresponding reductions in cross sectional area.

Table IV.4.3 Geometric elements of constricted channel sections

<table>
<thead>
<tr>
<th>Amt. of reduction</th>
<th>Flow (cms)</th>
<th>Depth (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Side slope (z: 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonconstricted</td>
<td>51.107</td>
<td>0.867</td>
<td>21.765</td>
<td>31.492</td>
<td>16.792</td>
</tr>
<tr>
<td>10%</td>
<td>51.107</td>
<td>1.072</td>
<td>19.589</td>
<td>28.342</td>
<td>16.792</td>
</tr>
<tr>
<td>20%</td>
<td>51.107</td>
<td>1.355</td>
<td>17.412</td>
<td>25.193</td>
<td>16.792</td>
</tr>
<tr>
<td>30%</td>
<td>51.107</td>
<td>1.754</td>
<td>15.236</td>
<td>22.044</td>
<td>16.792</td>
</tr>
<tr>
<td>50%</td>
<td>51.107</td>
<td>3.209</td>
<td>10.883</td>
<td>15.746</td>
<td>16.792</td>
</tr>
</tbody>
</table>

IV.4.2 Floodplain Comparison

For each constricted cross section, a new geometry file was created within HEC-RAS. As mentioned earlier, each cross section can be edited and plotted. This was accomplished by determining the coordinates of the modified sections in AutoCAD. The coordinates were entered into HEC-RAS and the constricted cross sections were obtained accordingly.
For each new geometry and corresponding water surface elevation, hydraulic computations were performed. The results were then exported as a *.gis file to ArcView using the post-processing application of the AVRas extension. The floodplains for each of the constricted geometries were computed, and an Avenue script was used to calculate the amount of inundated land. The results were tabulated and are shown below in Table IV.4.4.

Table IV.4.4 Change in inundated area due to reduction in cross sectional area

<table>
<thead>
<tr>
<th>Amt. of Reduction</th>
<th>Nonconstricted floodplain area (m²)</th>
<th>Constricted floodplain area (m²)</th>
<th>Additional area inundated (m²)</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>389998.26</td>
<td>393035.55</td>
<td>3037.29</td>
<td>0.78%</td>
</tr>
<tr>
<td>20%</td>
<td>389998.26</td>
<td>409585.81</td>
<td>19587.55</td>
<td>5.02%</td>
</tr>
<tr>
<td>30%</td>
<td>389998.26</td>
<td>455540.32</td>
<td>65542.06</td>
<td>16.81%</td>
</tr>
<tr>
<td>50%</td>
<td>389998.26</td>
<td>574242.95</td>
<td>184244.69</td>
<td>47.24%</td>
</tr>
</tbody>
</table>

As a means of visual comparison, Figure IV.4.5 displays the floodplains for both the non-constricted cross section and the cross section reduced by 50%.
Figure IV.4.5 Nonconstricted and 50% constricted floodplains
CHAPTER V
CONCLUSIONS & RECOMMENDATIONS

V.1 Conclusions

One of the objectives was to evaluate areas along the shores of the Charles Mill Lake to determine the optimal locations for disposing dredged materials for wetland development. A model using GIS was constructed for the project area, where data were acquired and effectively analyzed to produce a set of evaluation criteria as inputs for the multiattribute decision model.

A set of five evaluation criteria were developed within ArcView GIS that best utilized the data obtained. Multicriteria decision analysis techniques were investigated and successfully incorporated into the GIS that allowed for the development of the model that produced standardized commensurate map layers and criteria weights to select the optimal locations for sediment disposal sites.

Based on the evaluation result using the developed model, it was found that the optimal locations for wetland development include the MWCDs proposed disposal sites. The sites are concentrated within the northern portion of the lake mainly due to their close proximity to the proposed dredge channels. The preferred locations are focused around the interior shores or islands of the lake. Coincidentally, sites in these areas are also preferred for wildlife and habitat development.

Evaluation results using the developed model show that some locations near the lake inlet are suitable for disposal and wetland development. If sites are selected close to
the inlet of the lake, the criterion of backwater effects is used for further analysis in terms of optimization. To represent the placement of various disposal sites near the inlet of the lake, the cross section near the inlet was modified. Using GIS and the AVRas extension, outputs of the HEC-RAS computations can display changes of the inundated area due to the placement of disposal sites. It was found that the reduction of the cross sectional area would have little effect in terms of inundated area for record floods studied. As a result, only mean flow conditions were used in the evaluation for representing the placement of disposal sites near the inlet of the lake.

Using the same flow conditions, the water surface elevations were effectively determined by an iterative process developed within Excel. Results of inundated areas analyzed using ArcView GIS show that small reductions in the cross sectional area contribute to minimum increases inundated area. Given these results, disposal sites for wetland development may be placed near the lake inlet provided that the size of a selected site does not contribute to significant reductions of cross sectional area.

Because millions of grid cells were used, the complexity and number of calculations required for this study would have been impossible without the use of GIS. It not only serves as an information management and computation tool, but also acts as an excellent means of displaying geographically referenced information.

The developed model provides a means to utilize available data to determine preferred locations for dredged material disposal for developing wetlands. The evaluation is based on a logical and scientific process to assess potential disposal locations that otherwise would have been selected by relying simply on equipment constraints and costs. Similar procedures can be modified to investigate effects of lake
sedimentation and to determine the location of suitable sites that would minimize
environment impacts. Environmental consciousness was of utmost importance to make it
possible to enhance wildlife habitats while remaining cost effective.

V.2 Recommendations

The developed model was used to evaluate five parameters; water depth, distance
from the dredging operation, unsuitable land uses, distance from unsuitable land uses,
sand content within the lake substrate, plus the backwater effect for selecting optimal
sites for sediment disposal and wetland development. There are certainly other factors of
importance that are not included for consideration due to the lack of information. These
include properties of sediments such as moisture content, specific gravity, and
consolidation. Properties of the sediment samples will assist in the design of potential
disposal sites. They can easily be incorporated into the ArcView GIS for model
development used in the preliminary locating and sizing of disposal sites. Furthermore,
environmental requirements such as habitat and plant necessities could also be
incorporated into the model for assessing the final elevation of a site. Information of
time-varying factors such as bulking and consolidation/shrinking of the dredged materials
can also be included for estimating actual amounts of dredged materials for disposal.

The developed method is mainly to address the search for optimal disposal sites
utilizing dredged material for creating wetlands. However, the spatial analyses using
ArcView can also be used to develop methods for determining what areas need to be
dredged. Both the weighted-distance mapping and path analysis functions using
ArcView can easily be incorporated as a means of selecting the most appropriate areas to dredge. Additionally, by proximity mapping, sections of the proposed dredge channels can be assigned to proposed areas along the shoreline of the lake.

Furthermore, contents of sediment samples should be analyzed to assess suitabilities for plant and animal life for wetland construction. This may lead to modifications of the developed method in terms of treating contaminated materials. It is noted that the developed method assumes that all dredged materials can be used for wetland construction.

To achieve a better representation of the inundation area, it is suggested that channel surveys be conducted for the cross sections selected. This information will better express the results of hydraulic flow computations to show effects of inundation areas due to disposal sites located near the inlet of a reservoir.
References


Salzmann, H., “A Laboratory Study of Fluid and Soil Mechanics Processes During Hydraulic Dredging”, The University of Texas at Austin, Austin, TX, 1977.


